A Case Study on Human Tracking through Passive Wi-Fi tomography

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2017

A Case Study on Human Tracking through Passive Wi-Fi tomography

A dissertation submitted for the Degree of Master of Science in Information Security

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University of Colombo School of Computing

2017

Declaration

The thesis is my original work and has not been submitted previously for a degree at this or any other university/institute.

To the best of my knowledge it does not contain any material published or written by another person, except as acknowledged in the text.

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Signature: Date: 19[en] June 2017

This is to certify that this thesis is based on the work of Mr. E H G P N Abeywardane under my supervision. The thesis has been prepared according to the format stipulated and is of acceptable standard.

Certified by:

Supervisor Name: Dr. Chamath Keppitiyagama

Signature: Date:

Abstract

In the modern networking terminologies Wi-Fi plays a very important role which is a popular technology that uses radio waves to transmit data. In this research, it is mainly aimed on proof of concept for a Human Tracking with Wireless (Wi-Fi) tomography.

In my research, I used Radio Tomographic Imaging (RTI) technologies to prove that humans can be track by analyzing the wireless signals Receive Signal Strength Indicator (RSSI) value. The main concern of this research is by capturing the Wireless Signals of an indoor environment from outside the premise and generate a Radio Tomographic Image and find out the co-relation of captured data with the human behaviors of the interior environment. Through this study, I want to emphasis that without actually staying in the required environment, anyone can come into conclusion on human behaviors by capturing the signals by staying outside and nearby. The identifiable significant difference in the RSSI value is used throughout the imaging and analyzing process. For this I collected data on real world scenarios, analyzed them and used mathematical and statistical approaches for the analyzing part.

There are only limited number of research studies that have been carried out in this field. Thus, I have given an overview of investigating Human tracking that can be done in Wi-Fi band. This thesis is organized to show my research methods and knowledge obtained by analyzing the data in the above.

Finally, I hope the discussions which are focused on Radio Tomographic technologies and how humans can be tracked with Wi-Fi tomography may profit further studies in this field.

Acknowledgement

First of all, I express my sincere gratitude to my supervisor, Dr. Chamath Keppitiyagama for introducing me to this wonderful concept and for encouraging me and for all his guidance through the period of time which I was involved in my research. His proper guidance and advices were a significant feature that I received throughout the research which gave me the opportunity in achieving tasks in the given time frame.

Reviewing presentations, acquiring the necessary equipment or brainstorming about projects, his enthusiasm for helping with student's work by feeding new ideas and his genuine interest are exemplary and sincerely appreciated.

Apart from my advisor, I wish to express my thanks to Mr. Asanka Sayakkara and Mr. M.A.I.M Dharmadasa, who were continuously providing the guidance throughout the research and to finish this dissertation. Their continuous supervision on the practical aspects and application which are related to this field made a huge impact on me to achieve my goals.

I am also very much grateful to all my fellow staff members of Network Operations Center at University of Colombo School of Computing for the invaluable support given throughout my research.

I am also very much grateful to all my lecturers, assistant lecturers, demonstrators and other staff members of University of Colombo School of Computing for the great assistance given for me in numerous ways. Without all of them I could have never achieved this task.

Finally, I thank all my family members and all the other people which I haven't mention for their immense support in achieving this target.

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List of Tables and Figures

List of Abbreviations

AP	Access Point
CSI	Channel State Information
DFL	Device Free Localization
FFT	Fast Fourier Transform
NIC	Network Interface Card
OFDM	Orthogonal Frequency Division Multiplexing
RSS	Received Signal Strength
RSSI	Received Signal Strength Identification
SNR	Signal to Noise Ratio
Wi-Fi	Wireless Fidelity
WLAN	Wireless Local Area Network
WSN	Wireless Sensor Network

Chapter 01

INTRODUCTION

In the today's technological world, most of the data communication is done through the wireless technologies. These technologies are differentiating from one to another with the application and the way of the handling these technologies. The wireless waves are used electromagnetism to generate waves and propagate through the space. Also, the wireless technology usage domains can be categorized as public, industrial and military. At the presence, these wireless technologies are used for different perspectives other than the data communication.

X-Ray, Ultrasonic are one of the most common use of wireless technology in healthcare industry for medical application[1]. X-rays are used uses its penetration power for imaging. Magnetic Resonance Imaging (MRI) is a revolutionary imaging technology of wireless application in medical field[2]. It uses a magnetic field and pulses of radio wave energy to make pictures of organs and structures inside the body.

Radio Detection and Ranging Systems (RADAR), Global positioning System (GPS) and RFID etc. are some technologies used in the industry regards to the wireless technology application [3]. With GPS like localization application, can detect any object location with the higher accuracy. Also at the presence RF like technologies are commonly applied for authentication and localization mechanisms[4].

Wi-Fi technology is the most popular wireless network technology which use to connect millions of different devices to the Internet[5]. There are many emerging concepts which are based on the wireless (Wi-Fi) networks such as Smart Homes with use of Internet of Things (IoT) devices, Smart businesses, Smart cities etc.[6] To facilitate the network connectivity to these devices, Wi-Fi network infrastructure is highly populated throughout the world and become the most common wireless connection methodology in the community.

All these technologies use special transmitters and receivers to archive their task. While these are very effective and efficient technologies, the cost factor of implementing such a system is a huge challenge.

Radio tomographic imaging is a one of the emerging area of the wireless technology[7]. Tomography refers to imaging by sections or sectioning, through the use of any kind of penetrating wave. Figure 1 shows the RTI network which used for the radio tomography.

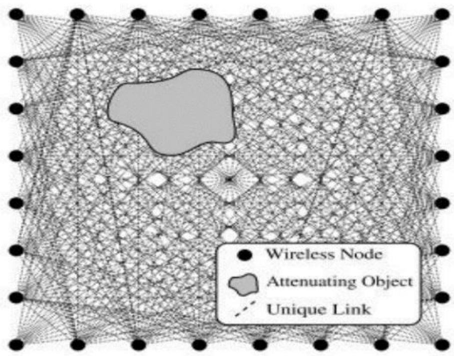


Figure 1 : An illustration of an RTI network. Each node broadcasts to the others, creating many projections that can be used to reconstruct an image of objects inside the network area [7]

Radio tomographic imaging (RTI) is an emerging application which offers a new way to image passive localization which enable to track any object without having any tracking equipment itself. Because of that Radio tomographic imaging (RTI) is also called “device free localization”[7], “passive localization”[8] or “sensor less sensing”[9].

Privacy can be introduced in many forms. One of the formation is freedom from interference or intrusion, the right "to be let alone," a formulation cited by Louis Brandeis and Samuel Warren in their groundbreaking 1890 paper on privacy [10]. Privacy will protect and prohibit the disclosure or misuse of information held on private individuals. Also there are privacy frameworks that are introduced in the world to avoid the privacy implications[10].

Currently Wi-Fi is coverage is extending in human populated areas and that causes most of the areas are covering with the Wi-Fi signals. These Wi-Fi signals can be penetrated using the RTI technology and able to generate passive localization of objects located inside that penetrated area.

1.1 Research Domain

1.1.1 Research Problem

Wi-Fi become the one of leading technology among the other wireless technologies by considering the current growth. Day by day, new innovations which are based on wireless technology will increase. Therefore, Wi-Fi has become the most common wireless technology among the users. Figure 2 shows the increment of wireless hotspots in the world with the change of years.

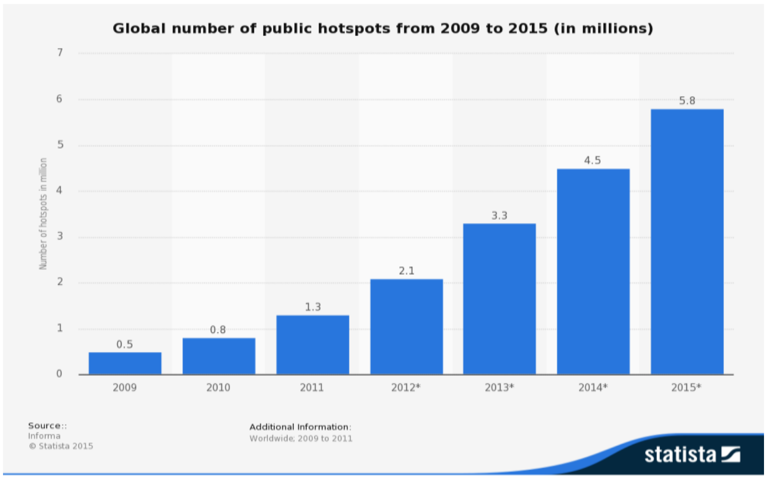


Figure 2 : Global number of public Wi-Fi hotspots from 2009 to 2015[23]

With the growth of Wi-Fi infrastructure to enable connectivity to the all Wi-Fi enabled devices, most of the public and private areas in the world is covered with the IEEE 802.11 Wi-Fi wireless technology. Each of these Wi-Fi enables devices communicate with other devices by using the wireless radio waves. Therefore, the covered area is filled with the Wi-Fi wireless signals which are coming from the transmitting and receiving devices.

Using the tomography technologies can be track the people locations, movements and behavior without letting them know that someone is tracking them by analyzing wireless signals. This method can be used as a security breach which is used to identify the human movements by tracking them through the wireless network. Also, this also violates the human privacy. Because without notifying them, RTI technologies help to monitor them.

1.1.2 Significance of the Research

The problem this research attempts to address is "How human objects can be detected through the passive Wi-Fi tomography?"

The identified problem is used to defend the security implication of the human behaviors and tracking them without their knowledge. Mainly this research is initiated to identify how human objects and their movements using RTI methodologies by correlate with the penetrated wireless signals which are coming from indoor environment to outside.

However the methodology can use for some industrial areas and military field as one of a security surveillance mechanism in the defense in depth deployment environment[7].

1.1.3 Goals and Objectives

The goal of this project is to analyze the general-purpose IEEE 802.11 Wi-Fi signals are coming from the indoor environment to the outdoor and generate a RT image to correlate with human objects using some predefined RT algorithm. With the use of generated RT image, try to determine how human objects can tracked through the passive Wi-Fi tomography.

1.2 Limitations and Assumptions

This research will be carried out to determine indoor environment object movement using Wi-Fi Signals coming from the indoor environment to outside through the walls.

The research is a case study based research which is consider only one environment not for the general environment. Because with the changes of the environment like wall thickness, wireless deployment mode etc. the results may be different than the case study environment.

Also, this study will prove the concept of object movements identification based on the RSSI values of the Wi-Fi signals using general purpose devices. In this case study the passive tomography method is use the changes in RSSI values of the Wi-Fi signals to determine patterns.

Within the study assume the environment setup has not been changed and only the objects movements are changed. Also, considered the environment factors like temperature, humidity etc. are constant throughout the case study. Also, the object and data gathering device is in line-of-sight with the transmitting base station.

1.3 Motivation

There are many security techniques and frameworks are implemented to preserve the privacy of a user's who are communicate through the general Wi-Fi network. The researchers are shown when an object moves inside the wireless network field, it causes the received signal strength indicator (RSSI) value to be changed or dropped regard to the movement [7]. These signals' changes can be used by the passive tomographic techniques to localize and identifies the movements of the objects.

Apart from the general usage of the Wi-Fi networks, cause of the technological changes leads Wireless technologies to help gathering some information through the sensor networks. These modern concepts are also covered the general environment with wireless networks. This rapid increase of the wireless networks is increasing the vulnerable areas for tracking human objects using some tomographic techniques.

Currently there is no any security mechanism is implemented to safeguard from human tracking through the passive Wi-Fi tomographic methodologies.

Within my research, will try to proof the concepts of human movements can be tracked through the wireless signals and that makes the concentration of security related personnel to implement to new mechanisms or framework to avoid these issues in the future.

Chapter 02

LITERATURE SURVEY

2.1 Radio Tomographic Imagine (RTI)

Tomography refers to imaging by sections or sectioning, through the use of any kind of penetrating wave. Radio tomographic imaging (RTI) is an emerging application which offers a new way to image passive localization of objects inside the buildings and outdoor environments using received signal strength indicator (RSSI) value[7]. Radio tomographic imagine has supported in many industries for different purposes. Mainly it uses for emergency and rescue operations, security surveillance systems and passive localization[11].

2.2 RSSI

The RSSI abbreviation is coming from the term Received Signal Strength Indicator. It is the value which provides the power strength of the beacon's signal as displayed in the receiving device. The RSSI value is vary cause by the distance, broadcast power and hardware vendors. At maximum Broadcasting Power (+4 dBm) the RSSI ranges from -26 (few inches) to -100 (40-50 m distance) [12]. Also, external environment factors likes’ interference of radio signals, absorption and diffraction etc. are trend to fluctuate the values of RSSI measurements.

The RSSI reading has no standardized affiliation of any particular physical parameter. Also, IEEE 802.11 standard has not provide any relationship between RSSI values and the power level measurements of mW or dBm. The hardware vendors and chip designers use their own granularity, accuracy and defined power and RSSI value ranges.

The RSS measurements which are taken by using the values of RSSI or dBm may be differ from each other. The dissimilarity is that RSSI is a relative index, while dBm is an absolute number representing power levels in mW (milliwatts)

2.3 Signal to Noise Ratio

Signal to Noise ratio is a measurement used in the science and engineering which compared the level of a desired signal to the level of carrier noise[12]. Normally it defined as the ratio between signal powers to noise power of a signal. In general, terms the signal and noise levels are measured using the measurements of watts or mill watts. The final value of the SNR is given by measurement in dB

There are many definitions for the Signal to Noise ratio, according to our purpose we took the definition of,

$$SNR = {}^{\mu}/_{\sigma}$$

Where μ is mean value of the signal and σ is the standard deviation of the noise.

2.4 Electromagnetic Waves

Electromagnetic waves are varying between frequency levels starting from the 3 kHz and ranging up to 300 GHz [12]. Electromagnetic waves are affected by many factors when they transmitting over the space. The major factors are,

- Signal frequency
- Transmission medium
- Obstacles or interference

These factors are resulting waves to gain the signals characteristics of reflection (the wave partially bounces of an object), refraction (change of direction when passing from one medium to another), absorption (loss of energy when an object is hit), diffraction (when waves are bend and spread around an obstacle), scattering (wave bounces off in multiple directions) and polarization (orientation of the oscillations of the waves can change upon interaction)

2.4.1 Wi-Fi

At the presence "Wi-Fi" become the most common wireless communication technology among the users. This use electromagnetic radio waves to provide high-speed Internet access and the network connectivity to the wireless enabled devices.

Wi-Fi technology is used commonly for local area wireless computer networks. Mainly Wi-Fi uses the unlicensed frequency bands of 2 GHz UHF and 5 GHz industrial, scientific and medical (ISM) radio band. With the unlicensed spectrum, wireless users are allowed to access the band without any regulations or restrictions. The major drawback of this unlicensed spectrum band is most of the users may share this band and it cause to increase the security vulnerabilities and resilient to intrusions like man-in-middle, spoofing and reply attacks etc.

LOWER FREQUENCY MHZ	UPPER FREQUENCY MHZ	COMMENTS
2400	2500	Often referred to as the 2.4 GHz band, this spectrum is the most widely used of the bands available for Wi-Fi. Used by 802.11b, g, & n. It can carry a maximum of three non-overlapping channels.
5725	5875	This 5 GHz band or 5.8 GHz band provides additional bandwidth, and being at a higher frequency, equipment costs are slightly higher, although usage, and hence interference is less.It can be used by 802.11a & n. It can carry up to 23 non-overlapping channels, but gives a shorter range than 2.4 GHz.

Table 1 : Wi-Fi Frequency Ranges for 2.4GHz and 5GHz

Table 1 shows how Wi-Fi frequency band variations is occurring between 2 GHz and 5 GHz in ISM radio band frequency range. In the following Table 2 figure shows how the 2 GHz frequency ranges are divided into wi-fi channels.

CHANNEL NUMBER	LOWER FREQUENCY MHZ	CENTER FREQUENCY MHZ	UPPER FREQUENCY MHZ
1	2401	2412	2423
2	2404	2417	2428
3	2411	2422	2433
4	2416	2427	2438
5	2421	2432	2443
6	2426	2437	2448
7	2431	2442	2453
8	2436	2447	2458
9	2441	2452	2463
10	2451	2457	2468
11	2451	2462	2473
12	2456	2467	2478
13	2461	2472	2483
14	2473	2484	2495

Table 2 : 2.4 GHz Wi-Fi Channel Frequencies

The standard which are compliance by the Wi-Fi technology is defined in the IEEE 802.11 specification. In these standards includes MAC and physical layer specifications which are required in the implementation of the WLAN.

2.5 OFDM

Orthogonal Frequency Division Multiplexing is abbreviated as OFDM [14]. OFDM is one of the multiplexing mechanism which done a single channel utilization to multiple sub-carriers on adjacent frequencies using frequency division technique. With the OFDM multiplexing mechanism, it increases the spectral efficiency[12].

In general overlapping of adjacent channels are causing to create interference to each other. But sub-carriers in an OFDM multiplexing system are precisely orthogonal to one another. Because of that overlapping among them occurs without any interference. Therefore, OFDM systems are working more efficiently in the spectrum with the usage of sub carriers. Figure 3 describes how the channel hopping works in 802.11 wireless system.

OFDM is more concentrate on the implementation of wireless standards like IEEE 802.11a, IEEE 802.11b, IEEE 802.11g, IEEE 802.11n and IEEE 802.11ac and more. With standards adoptions to the deployments trend data transmission to archive some advantages like high speed etc.

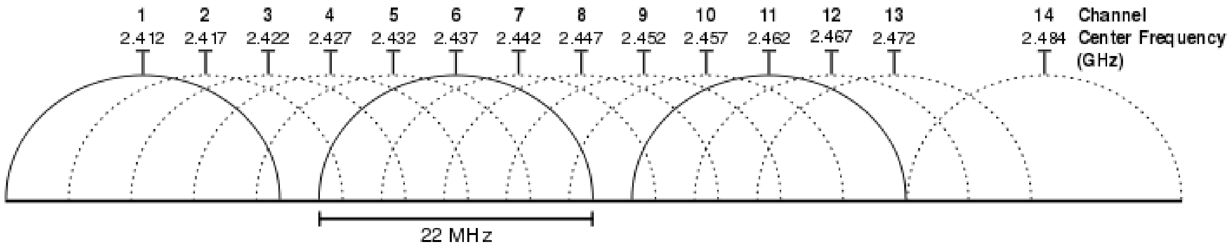


Figure 3 : IEEE 802.11 wireless channel hopping frequencies

2.6 Related Works

2.6.1 Privacy and Security Implications on Wireless (Wi-Fi) Tomography [15]

In this research proofed how security and privacy violation are depends on passive Wi-Fi tomography inside the indoor environment by analyzing RSSI values and statistical knowledge derived from the RSSI values.

The setup is used the general infrastructure mode wireless deployment in the indoor environment and for receiver, use the standard wireless card for data capturing purpose. Using some python scripts, collect the fluctuation of RSSI values caused by the human movements regards to the several real-world scenarios. Figure 4 shows how the python script generate RSSI values fluctuation as graphical output.

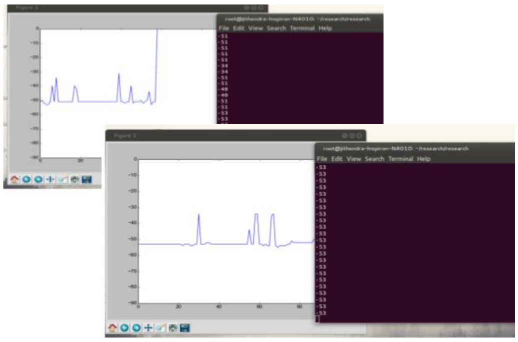


Figure 4 : Capturing RSSI data using the python script

The captured data processed with statistical hypothesis testing function to derive the knowledge to identify the human movements. With this statistical method, can able to identify the significant changes in the data distribution of RSSI values.

By looking at these results derived from the statistical model, can determine the person's locations and presence with the probability more than 50%. So, it can proof the concept of wireless tomography inside the indoor environment. Also, it concludes, by using this methodology humans can be tracked without letting them know and it causes the privacy implications due to passive Wi-Fi Tomography.

2.6.2 Investigation of Privacy Violations in Wi-Fi Band Using Software Defined Radio [16]

In this research consider the privacy violations which are caused by the passive wireless tomography. In here mainly consider the fluctuation of the FFT (Fast Fourier Transform) values which causes by the human movements inside a building to localize the human objects. The data is also collected by from the inside of the building.

Within the research the testbed is created with infrastructure mode wireless deployment and in the receiver side, the special hardware called "HackRF" device is used to capture the signals. It has the capability of transmitting and receipting radio signals from 1 MHz to 6 GHz as a Software Defined Radio peripheral and the device is supported to operate in half-duplex mode. Furthermore, within the research used a static frequency range (channel 1, 2.412 GHz) and also limited the signal transmission rate to 20%. Following figure shows how GNU radio presented FFT value variations as real-time graph

Figure 5 : Real time FFT data plot created by GNU Radio

With the variations of this FFT values can derive the human presence and it uses to relate with privacy and security violations with in the wireless network.

These Privacy and Security Implications on Wireless (Wi-Fi) Tomography [15] and Investigation of Privacy Violations in Wi-Fi Band Using Software Defined Radio [16] literatures are more related to my research. Because these are the bases of my research and my work is extended using these base researches.

Mainly with these two researches, authors have been proved the Tomographic concepts with the use of special hardware devices and generic wireless system. Also, they could able to present the drawbacks and findings with the use of their methodologies.

For my work, I have used general purpose devices such as generic access point devices, wireless card devices etc. to collect data and continue the research. But in the above researches they used special devices. Also, they have collected data by staying in that environment. For my case, it become different and collected RSSI data which were coming from inside building by staying in outside the building. Apart from that as a final output, I could able to generate radio tomographic image for the testing environment to track the human objects located inside environment. But in above researches they couldn't do it.

2.6.3 Radio tomographic imaging with wireless networks [7]

Radio tomographic Imaging (RTI) is a technology which used for image the attenuation caused by the physical objects in a field of wireless network. In this research is based on the shadowing losses on links between many pairs of wireless nodes in a network and use that information to map the objects movements within the network area.

The measurements of the link losses are taken as received signal strength (RSS) values. By analyzing the variation of the RSS values which are collected from the paired of wireless nodes, can able to get aware of the actual object location within the wireless field.

For this research 28 of wireless peer-to-peer nodes are deployed purposely with in the perimeter of a 21x21 foot square area [Figure 01]. Each of the node are broadcasting signals to peer nodes. When objects are moving inside the wireless area, the links between the pair of nodes are intersect and it trends to change the RSS vales of affected nodes. With analysis of the variation of RSS values, the RT image is generated by mapping the objects locations within the wireless network.

2.6.4 Whole-Home Gesture Recognition Using Wireless Signals: "WiSee" [17]

WiSee is a novel gesture recognition system which uses the wireless signals to enable whole-home sensing and recognition of human gestures. WiSee use the property of Doppler Shift to obtain its objectives. Doppler Shift is the changes in an observed frequency of a wave, when the transmitter and the receiver moves relatively to each other. For the WiSee perspectives, when user changes the movement of his gesture, it makes small changes to the frequency of wireless signal. When user moves his hand at the rate of 0.5 m/s the frequency shift it generates is 17Hz.

WiSee is implemented by using GNU Radio and the special hardware device called USRP-N210s. It can help to detect even a small change in the frequency of a signal with high accuracy. Also in the real-world scenarios, multiple people can be affected to the signal changes at a same time. WiSee uses the MIMO capability inherit to the IEEE 802.11n wireless to determine gestures from the specific individual. MIMO provide multiple transmitters to broadcast signals to MIMO receiver. To treat the reflection signals which are actually coming from the humans, MIMO receiver uses multiple receivers to separate individuals.

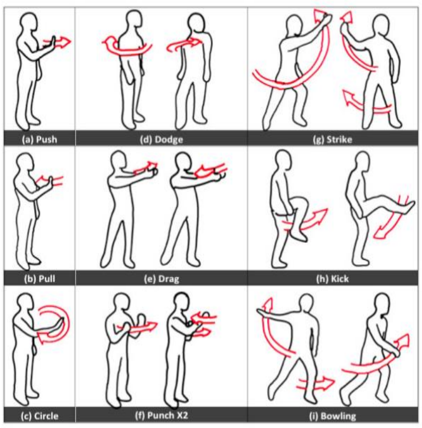


Figure 6 : Gesture sketches: WiSee can detect and classify these nine gestures in line-of-sight, non-line-of-sight, and through-the-wall scenarios

WiSee can identify the nine whole-body gestures shown in the figure 6 with average accuracy of 94%. These gestures are identified by using 900 of different gestures. With the use of 4 receiving antennas and one transmitter, WiSee enable to classify above gestures with the accuracy of 64%. With the use of 5-receiving antennas and one transmitter, can able to classify three different users' gestures which are performed by randomly.

2.6.5 RADAR: An In-Building RF-based User Location and Tracking System [18]

Paramvir at al. conducted this research to create a system for locate and track the objects in the inside of a building using RF networks in the year of 2000. This research is based on empirical signal strength measurements as well as a simple yet effective signal propagation model. The empirical model is providing the terms of accuracy and the signal propagation model make the deployment easier.

The testbed environment is consisting with three base stations and one mobile host which is carried by the user. Each base stations and mobile host was configured with the "Digital RoamAbout™" network interface card (NIC), based on Lucent's popular "WaveLAN™" RF LAN technology. The WaveLAN driver helped to extract the Signal Strength (SS) and the Signal-to-Noise Ratio (SNR) information at the time when the broadcast packet is received by the base stations. The RF network is running under 2.4 GHz unlicensed ISM band. The range of the network, as specified in [Roa96], is 200 m, 50 m, and 25 m, respectively, for open, semi-open, and closed office environments.

Each of the base station is covering the major overlapping portion of the building floor and together with three base stations, covered the entire floor area with RF network. See the following figure 7 for test bed setup.

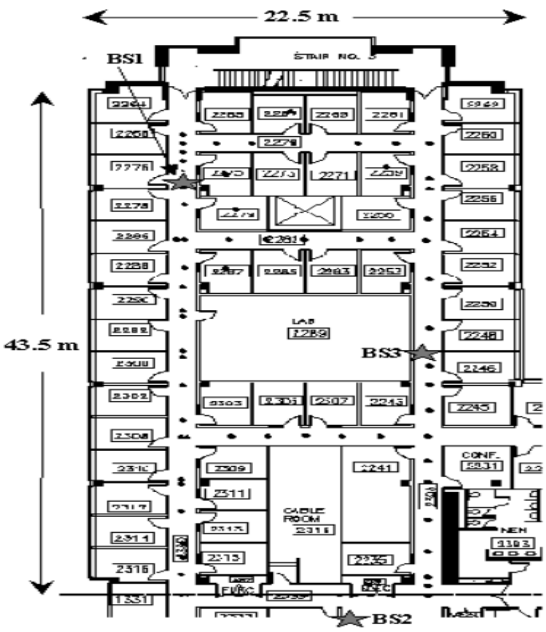


Figure 7 : Map of the floor where the testbed was created and the black dots denote locations were empirical signal strength information was collected. The large stars show the locations of the 3 base stations. The orientation is North (up) and East (right)

The mobile host is transmitting 4 UDP broadcast packets with the 6-byte payload per seconds. Each base station (bs) record the signal strength (ss) together with the time stamp (t). This information were recorded as a tuple form of (t, bs, ss). Also the mobile host is recording the data time stamp (t), user coordinates (x,y) and direction(d) for further evaluation.

The Nearest Neighbor(s) in Signal Space (NNSS) technique is used to evaluate the analyzed data. It is filtered the multiple locations that was identified in the analysis process and help to pick one of the best location that matches with the received signal strength. Figure 8 is used for get signal strength against distance for the base stations.

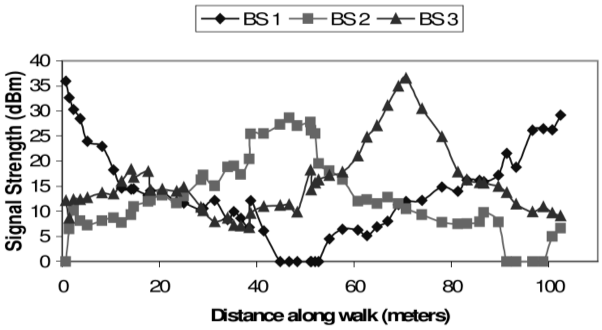


Figure 8 : Signal strength recorded at the three base stations as the user walks around the floor

The RADAR system can detect the locations with the accuracy in the range of 2 to 3 meters with respect to the size of the building. Therefore, this results indicates location-awareness services can build with RF wireless LAN with higher accuracy.

2.7 Related Products

2.7.1 See through the walls: hand-held radar system

See through the walls is a hand-held device which is developed to deploy in emergency situations. This is a commercially available product around the cost of $6000USD - $7000USD and this is developed by “Camero-Tech Ltd” and their product-line called “XAVERTM”. This product is mainly used by military and law enforcement agencies to obtain tactical advantages over emergency situations. Figure 9 shows how hand-held radar device is operating.

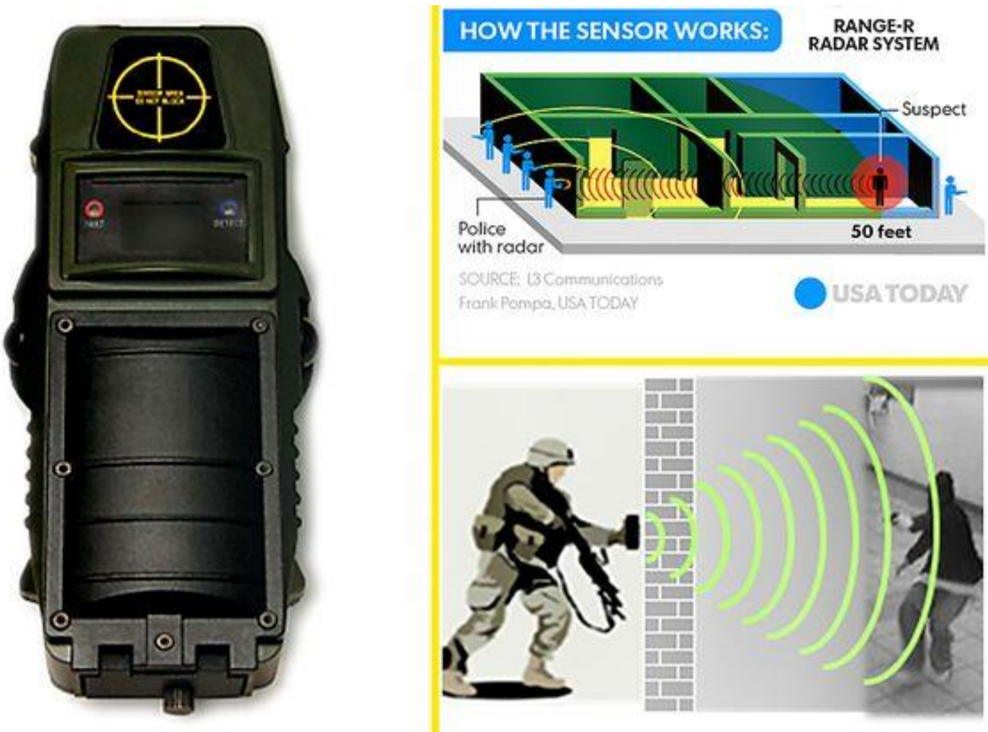


Figure 9 : The hand-held Radar equipment developed by Camero-Tech Ltd.

This device is developed by using the micro power Ultra-wide band sensor which helps to operate in high bandwidth and enable to detect the obstacles with the high accuracy[19].

The characteristic of wave reflection is used to identify the objects in inside the buildings. The device transmits radio waves through the walls and wait for reflected signals coming back to the device which are reflected from objects. By reading of this information derived from the received signals, can able to identify no of objects and their locations and orientation of inside the building by without entering to the building.

2.7.2 Google project: "soli" [20]

"Soli "is a project initiated by the Google research team to create a microchip which has an ability to identify human hand movements and hand gestures. The "Soli" has contain a sonar sensor which can able to track even sub-millimeter motion with high accuracy and speed. The sonar sensor is embedded to the chip and complete chip can be produced at any scale for use in even some small wearable devices.

The radar waves are used here to detect the movements and gestures because radar waves are easy to optimize for detecting the small variations in the hand gestures [Figure 10].

Each of the gestures are identified by using the unique signal pattern which are derive from the received signal [Figure 11]. The patterns are already identified and stored as a pattern dictionary. When a unique pattern is identified, the chip can perform pre-programed action in the application regards to the pattern.

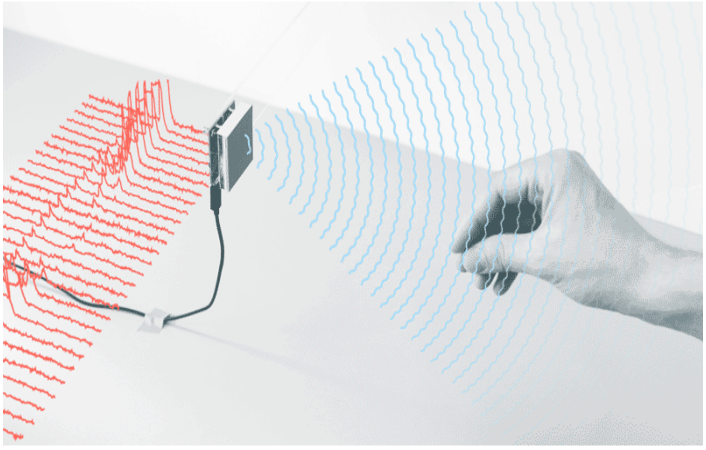


Figure 10 : How the project soil is working

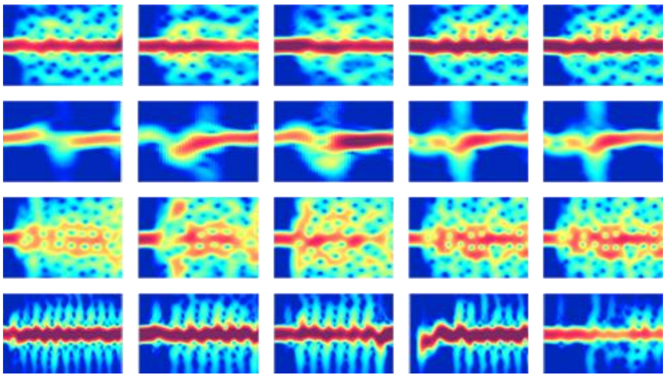


Figure 11 : Sensor data showing four gestures performed by five users

Chapter 03

DESIGN AND IMPLEMENTATION

Electromagnetic waves are propagating through space, there are numerous chances for these waves to get affected by various effects. The consequence of these effects mostly is a function of signal frequency, transmission medium and objects come across during propagation [12].

Aforesaid effects consist of

- Reflection (when the wave partially bounces off an object),
- Refraction (change of direction when passing from one medium to another),
- Absorption (loss of energy when an object is hit),
- Diffraction (when waves are bend and spread around an obstacle),
- Scattering (wave bounces off in multiple directions) and
- Polarization (orientation of the oscillations of the waves can change upon interaction).

In addition, in free space electromagnetic waves are following the inverse-square law

"The power density of the signal is in inverse ratio to the square of the distance from the transmitter"

Multi-path propagation is another aspect to be considered in radio wave propagation. Usually antenna of the transmitter discharges radio waves in various directions (e.g. Omni-directional antenna) or angles (e.g. directional antenna). In addition, some of above mentioned effects tend to take place at the same time. For an example, there is a possibility for a radio wave to propagate through an object but part of it will be reflect on its surface and some of its energy is captivated by the object. This interplay causes to produce at least two signals which are propagating in different directions but originating from the same source. Radio signals that are generated from the same source, which reach the receiver by two or more paths, are labeled as multi-path signals or components. In general, the summation of some of these destructive or constructive multi-path components is the power of the received signal.

The power of the received signal is indicated usually by a single parameter available in wireless and sensor networks. This is called as the received signal strength indicator (RSSI). In general, it is a scalar value. This parameter can be accepted as an intricate function of the above described effects more than the course of the signals through space until entering the receivers' antenna.

One of the major process is data gathering for this research and scenarios are used to generate the real-world examples. Finally do the analysis by using the collected results/data through the scenarios of the project.

In this research, the process was carried out through four main phases. The main reason for widening the research for many steps is due to what observed in each phase as well as the obstacles faced can be used to prevent errors in further phases and also it will properly direct to the expected output through the step by step process.

3.1 Hardware Devices

3.1.1 Infrastructure mode (Controller-based WLAN)

WLAN can be deployed by using two different architectures, the peer-to peer mode (ad-hoc) and the Infrastructure mode. Most of the industrial deployments are based on the infrastructure mode which are basically known as controller based wireless implementation. Within this implementation the main device is called as the Controller node and the other service devices are called the Access points. [21] Figure 12 shows how the how the infrastructure and Ad-Hoc model is differentiating from each other.

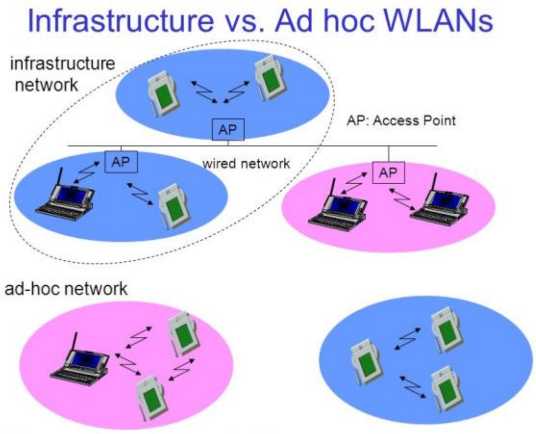


Figure 12 : Infrastructure and ad-hoc mode in WLAN

The access points are working as a wireless hub to provide connectivity between the wireless controller and the end user devices. The controller node is the management and the processing unit of the WLAN. The functionalities of the wireless controller are Authenticate, associate wireless clients who are connected through the wireless access points, wireless packet switching and routing, security management, AP management and Load balancing etc. Within the association, controller can manage the SSID related functionalities, frequency hopping with channel selecting. For the authentication function controller provides authentication mechanisms, authentication protocols and authorization information etc.

In my research, the infrastructure mode WLAN deployments is used as my testbed environment.

3.1.2 Access Points

WLAN is the device which supports end users to connect with the wireless network. AP is working as a station which sending and receiving the data and also working as an interconnecting device which bridge the Local network and WLAN. [21]Each AP can able to handle several wireless clients at the same time within the wireless network area. No of users can be handled is differentiate from vendor to vendor. Also, when users are roaming between the locations, APs have ability to change the clients between the APs. Figure 13 shows the Infrastructure mode AP which used for the testbed setup.

Figure 13 : Infrastructure mode Wireless Access point AP-105

The clients are connected with the space called cells, the cell sends probe requests on each channel. The probe requests are containing the information of ESSID which cells are allowed to use the channels. Within the regular intervals, each access point broadcast a beacon signal which contain the details of BSSID also the ESSID by default. When BSSID and traffic information are matched, AP sends the synchronization response to clients for asking to send their data. This is how the base stations and APs are communicated.

The data rates are varying with the distance between the base stations and the Access points because of the signal strength variations. Also, the clients are connected to the access points by considering the best capacity, current load and signal strength provide by the AP.

3.1.3 Signal Capturing Device

My research is required the received signals RSSI values for identifying the human movements within the wireless network. For retrieving this RSSI values, use general purpose laptop with Intel® Dual Band Wireless-AC 3165 dual band wireless card. This wireless card is supported the wireless standards of IEEE 802.11abgn, 802.11ac, 802.11d, 802.11e, 802.11i, 802.11h and 802.11w. Below figure 14 shows the wireless card which used for capture RSSI values.

Figure 14 : Intel® Dual Band Wireless-AC 3165 dual band wireless card

This card is supported to work in both 2 GHz and 5 GHz unlicensed ISM bands, provides improve channel reliability resulting in better coverage and performance, fewer dropped connections, less congestion, and more speeds further away from the router.

3. 2 Design Phases

3.2.1 Phase 01: Testbed preparation

In the initial stage prepare the hardware setup in the UCSC laboratory environment to capture the wireless signal changes using RSSI. Mainly the area is consisting with computer laboratory and assume the all objects in this area is not moved during the research data is collecting. Figure 15 shows initial test bed environment setup and dimensions.

Figure 15 : Testbed environment setup with wireless AP, receiver

Use the following equipment for deployment of this setup. Also, assume the Wi-Fi signals are generated only from the AP inside the room.

i. Aruba 3400 WLAN controller
ii. Aruba AP-105 series access points
iii. Dell inspiron i3 7000 general purpose laptop with Intel® Dual Band Wireless-AC 3165 dual band wireless card

Using this hardware setup, will be conduct scenario based data capturing to collect RSSI based data for further analysis in the next design phases.

3.2.2 Phase 02: Data collection

In the design phase two, the data will be collected by using the real-world scenarios which are developed to identify the human movements inside the room.

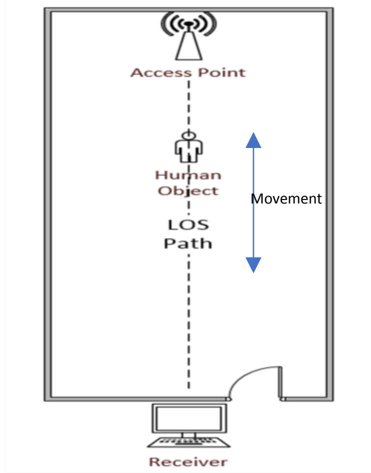


Figure 16 : Sample Scenario 01

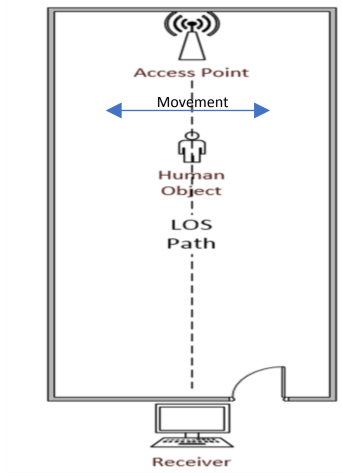


Figure 17 : Sample Scenario 02

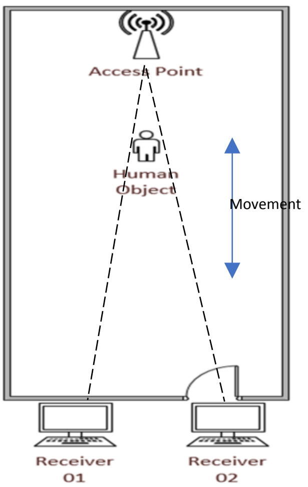


Figure 19 : Sample Scenario 03

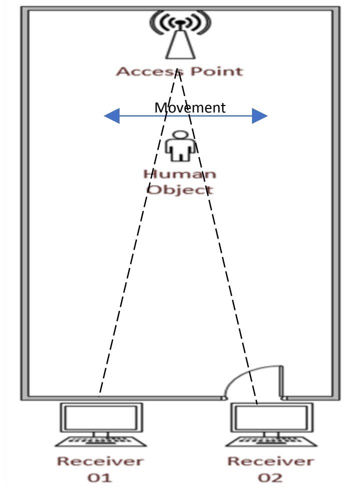


Figure 18 : Sample Scenario 04

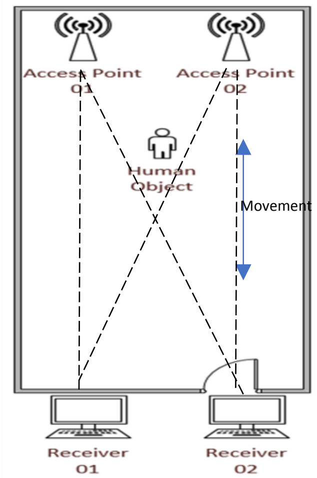


Figure 21 : Sample Scenario 05

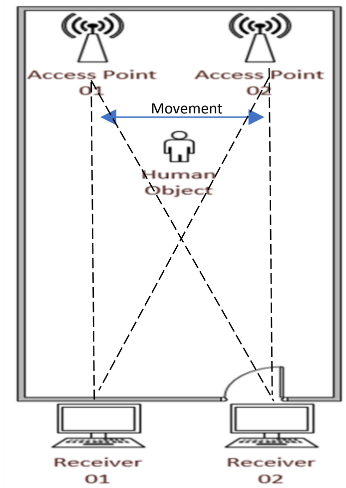


Figure 20 : Sample Scenario 06

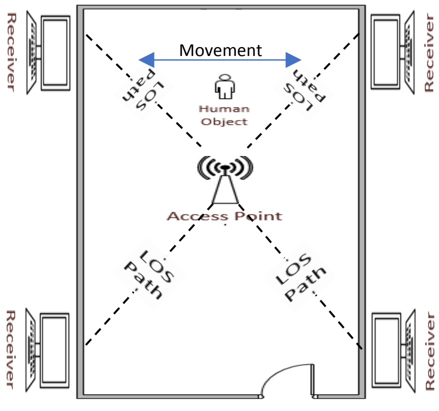


Figure 23:Sample Scenario 07

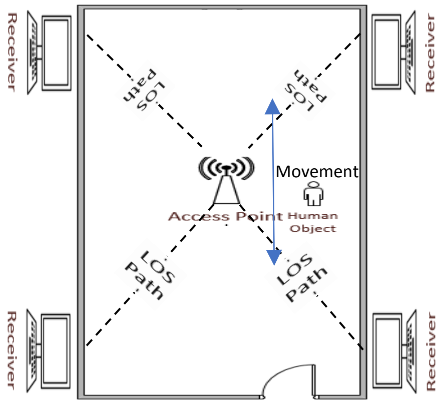


Figure 23: Sample Scenario 08

Figure 16 to 23 show the sample test bed preparation scenarios which were used for the data collection. These are some sample figures and full scenario list is attached in the Appendix A and the data collecting script is attached in the Appendix B

The scenarios are optimized with the analysis of the collected data and change the scenario with the required changes to increase the accuracy of capturing process. The following areas need to be change in the future scenarios regards to the knowledge and difficulties have faced in the previous data collection scenarios,

i. Change the no of wireless access points in a scenario
ii. Change the access point Location
iii. Change the no of Wi-Fi receivers in the scenario
iv. Change the human movement characteristics such as speed, direction etc.

In this data collection process. I have setup each scenario and collected RSSI data from outside of test environment. For an example, figure 16 shows data collection scenario 01. In that scenario, one access point was fixed in middle of furthest wall and receiver was arranged in outside of the nearest wall from the door which describes in figure 16. The AP and receiver were arranged in line of sight. As the initial point, I have taken RSSI data without any human object inside the room as calibration point. Data collection time duration was around 10-15 mins.

As next step, one human object was placed inside the room and taken the RSSI values from outside. Human object was moving between the AP and receiver during the data collecting time. Like this, collect two separate RSSI data values for each scenario with and without human objects. In the Data analysis phase, these two RSSI data points will use to derive changes in RSSI vales regard to movements of the human object.

The scenario list was developed to cover all possible room arrangements with access points and to create maximum links between APs and receivers which covers the whole test environment. Also, human object was placed to cross multiple links between access points and receivers as describe in above figures for get considerable amount of changes in RSSI values.

3.2.3 Phase 03: Data processing and manipulations

In this phase, the collected data from the previous phase is processing to determine the signal pattern to identify the human movements. The workflow of this process can be expressed by using following flow chart.

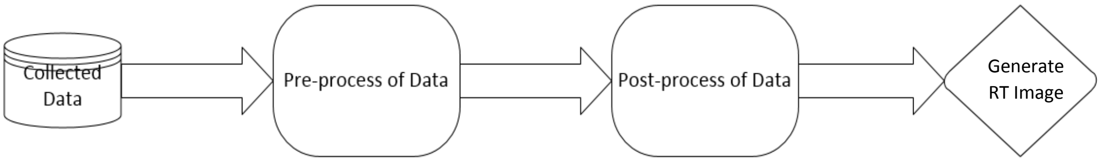


Figure 24 : Workflow of the Data Processing Phase

In the pre-processing process, all the collected data will be pre-processed using noise filtering algorithms like moving average, Gaussian filters etc. with the application of filtering algorithms, the noise of the data will be removed partially.

In the next step the RSSI fluctuation will be calculated using the pre-processed data. The basic calculations of the RSSI data is data distribution using the support of mean and standard deviation values. One of other calculation is get the SNR value from the collected data. With the SNR, the variation of the RSSI can be calculated as the data distribution.

As the final stage, analyze the derived data from the post processing phase and generate wireless RSSI fluctuation patterns to classify the human objects location by generating a radio tomographic image.

3.2.4 Phase 04: Human object localization and Evaluation of research

With the use of the generated RT images in the previous phase, will correlate the human track due to the passive Wi-Fi tomography. In the evaluation, the following main criterions are evaluated,

i. Accuracy of the object identification

   In this stage evaluate the results will be evaluated to find out, at what level of accuracy can be achieved when detecting human objects using the RTI methodology.

ii. The effect of human localization through the passive Wi-Fi tomography

   In the second evaluation criteria, will evaluate the results for identify the human object movements with the use of Wi-Fi tomography. Mainly in this stage correlate the generated RT images which are derived from the RSSI fluctuation data with human movements.

Chapter 04

ANALYSIS AND EVALUATION

Within this chapter gathered data which are collected from the previous stages will be processed and analyzed to derive some meaningful outputs regards to Radio tomography.

Mainly as the first step going to prove the tomographic concept for my testing environment. In this process going to get use of Standard deviation based analysis and Signal to Noise ratio based analysis. Standard deviation is a measure of the spread of scores within set of data set. Therefore, within this analysis phase, standard deviation is used as one measurement for get RSSI values fluctuation of collected data. Using standard deviation, we can present these set of data with better description. With the SNR methodology, data will be compared with the level of Wi-Fi signal and level of background noise.

As final step applies the patwari's mathematical model to collected data to generate Radio tomographic image for the testing environment for answer the research question. This patwari's model is already existing model and this model is changed accordingly to suite with my requirements.

For the each of scenarios collected ~10-minutes data which contain more than 2000+ RSSI values and all graphical outputs of data will be attached in the Appendix C.

Mainly the data is collected with the support of python scripts (See the Appendix B) which runs under Linux machine. All the hardware components are general purpose devices which are already mentioned in the previous chapter.

4.1 Analyzing RSSI Data

4.1.1 Standard Deviation based analysis

Within this phase, captured raw RSSI values for each scenario is analyzed and evaluated using a statistical approach to verify the Radio Tomography is effected successfully in our testing environment.

As the first step RSSI data will be plotted into normal distribution graphs by using the standard deviation values. With the use of these graphs, can check the RSSI data variation regards to each scenario. The generated graphs will be presented as follows and the legend of the graphs will be,

X axis – Received signal strength (RSSI) value

Y axis – Normal distribution value

From figure 25 to figure 46 shows graphical representation of standard deviation for the collected data. With this graphical representation, RSSI value population can be identified and can be able to determine outlier values through variation of graphs.

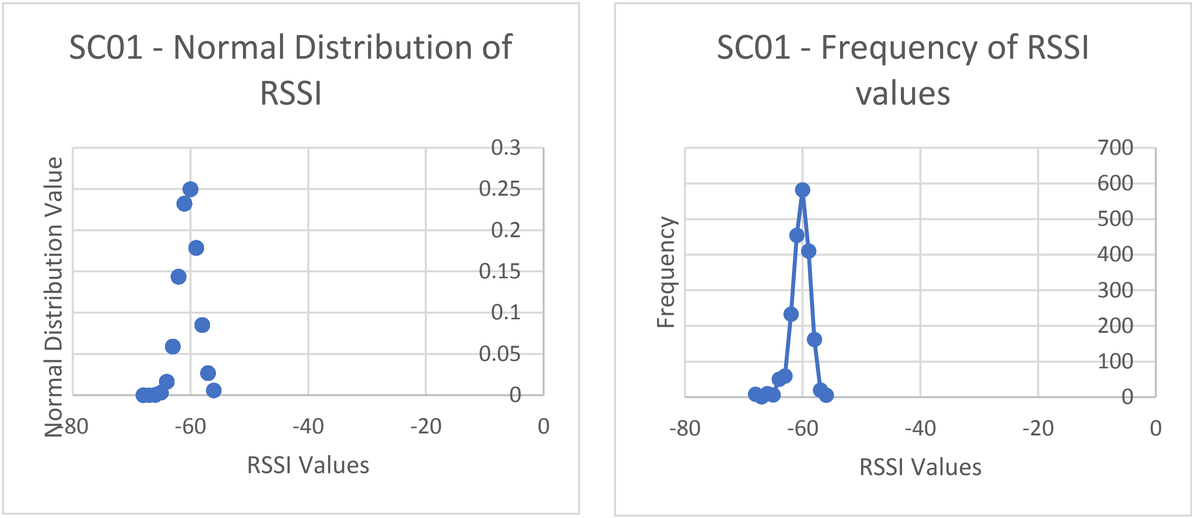


Figure 25 : SC01 Normal Distribution and frequency variation of RSSI values

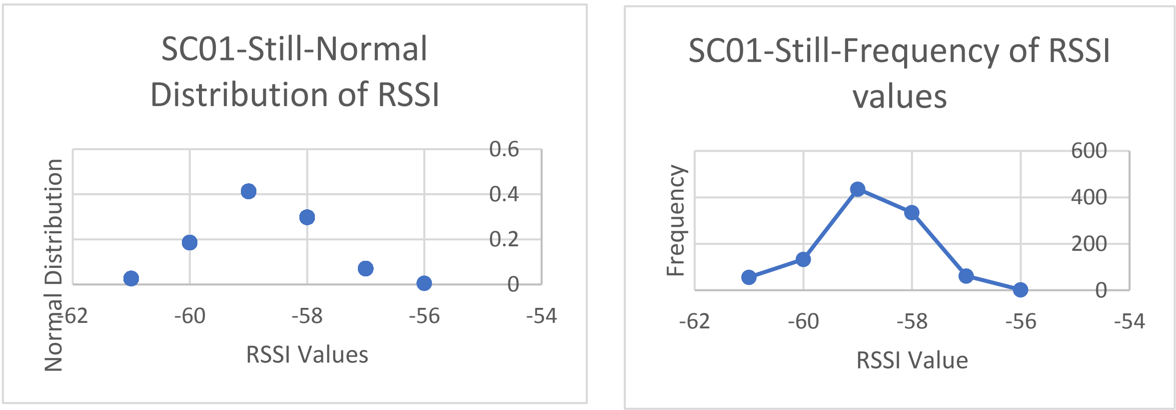


Figure 26 : SC01 Normal Distribution and frequency variation of RSSI Values without movement

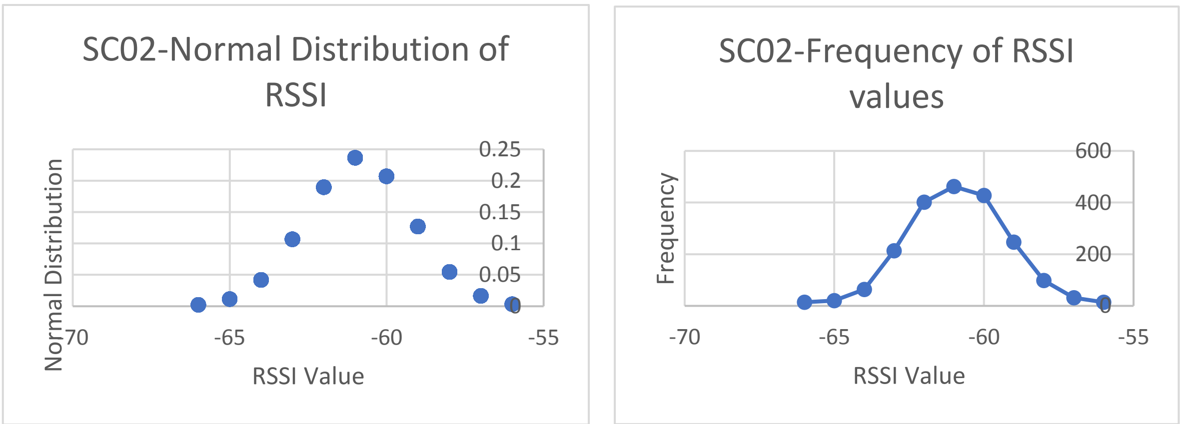


Figure 27: SC02 Normal Distribution and frequency variation of RSSI value

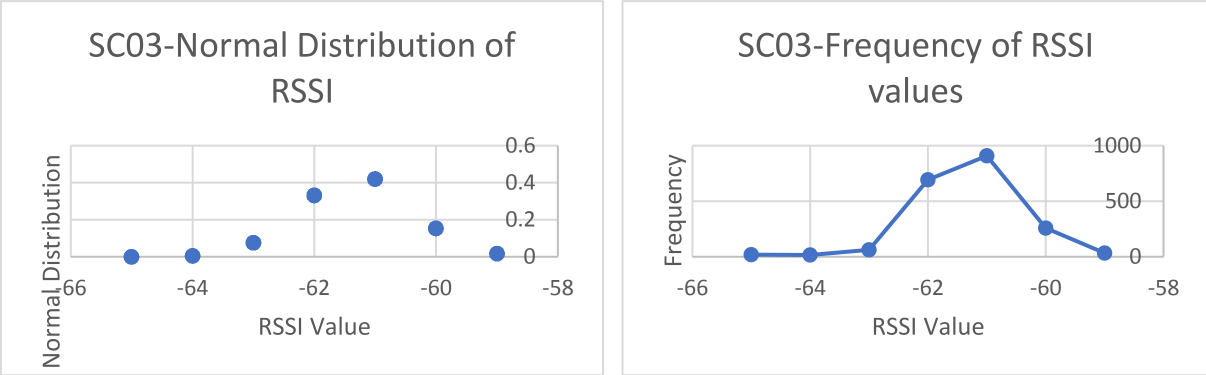


Figure 28 : SC03 Normal Distribution and frequency variation of RSSI value

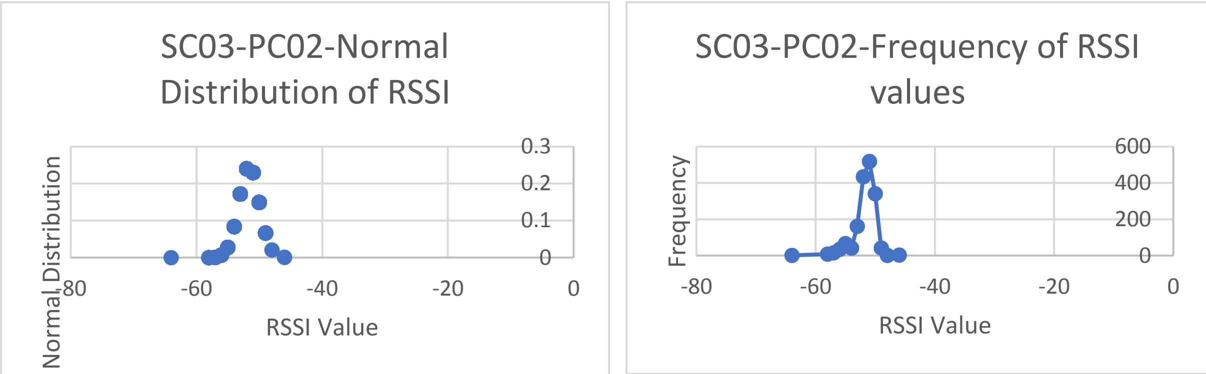


Figure 29 : SC03-Reciever 02 Normal Distribution and frequency variation of RSSI value

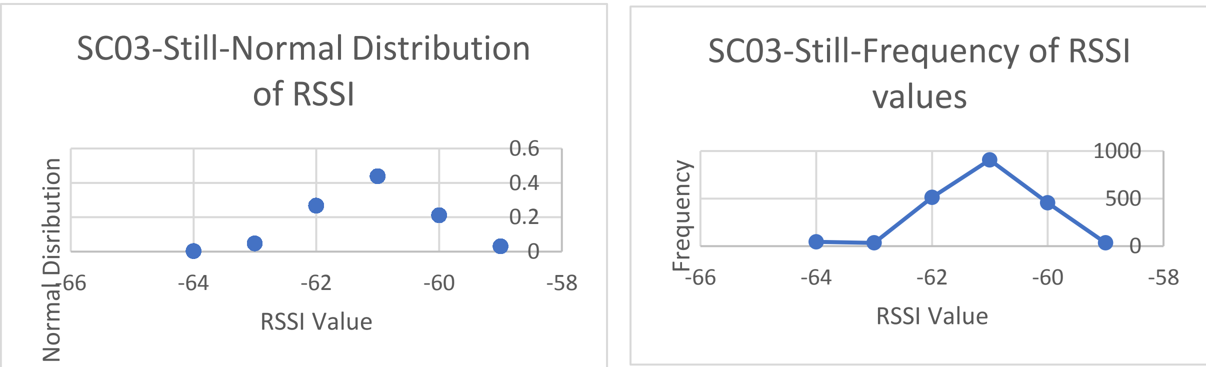


Figure 30 : SC03 Normal Distribution and frequency variation of RSSI Values without movement

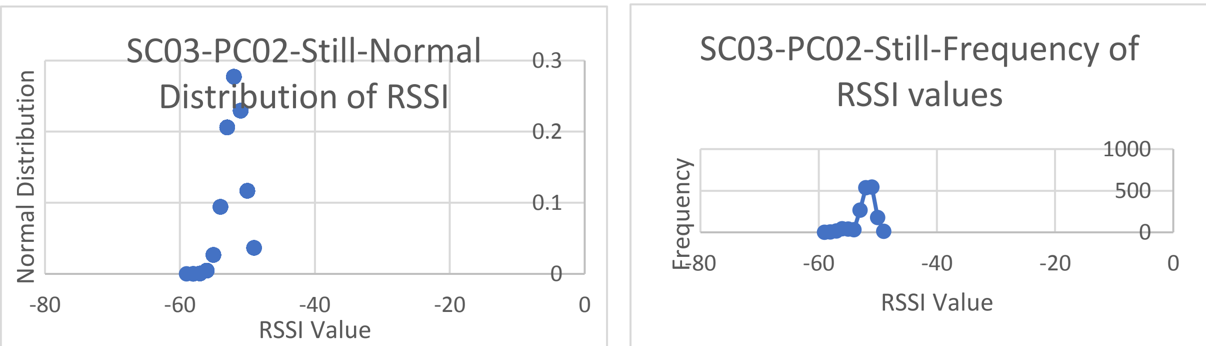


Figure 31 : SC03-Reciever 02 Normal Distribution and frequency variation of RSSI Values without movement

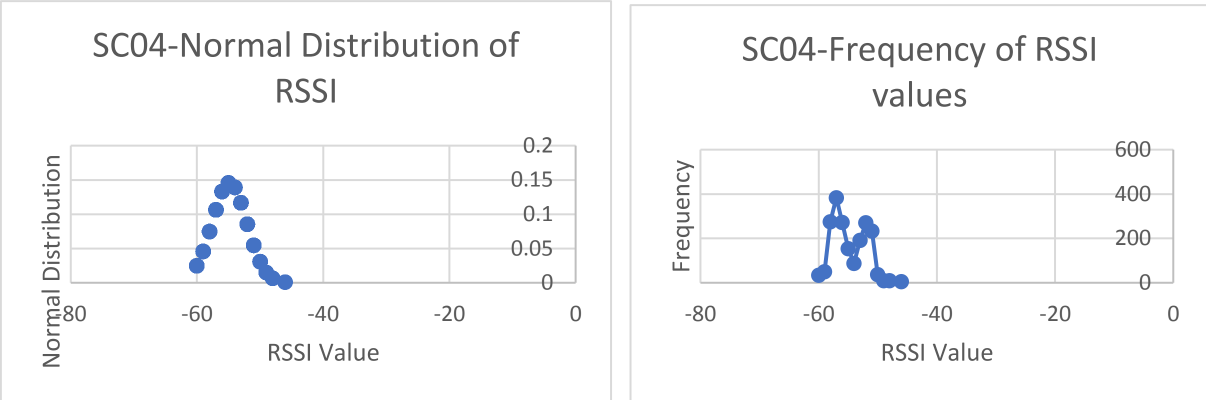


Figure 32 : SC04 Normal Distribution and frequency variation of RSSI value

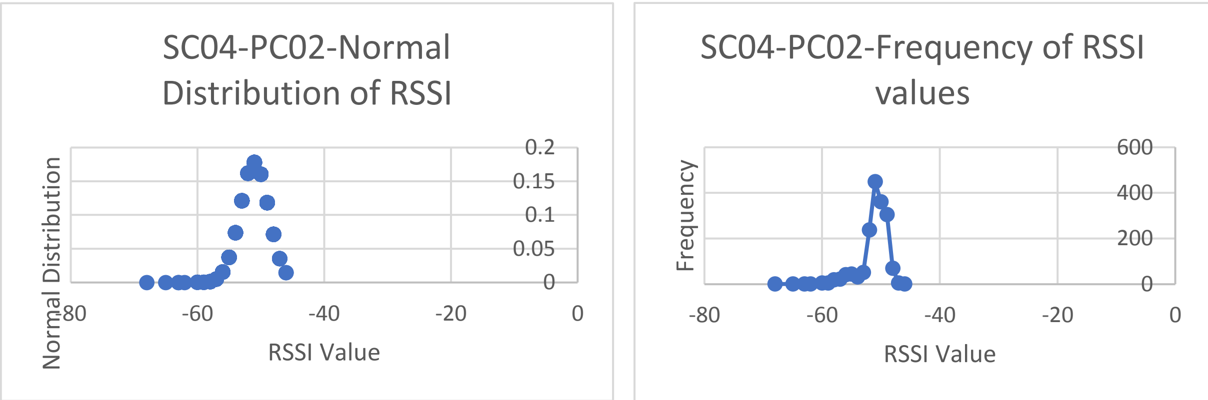


Figure 33 : SC04 Receiver 02 Normal Distribution and frequency variation of RSSI value

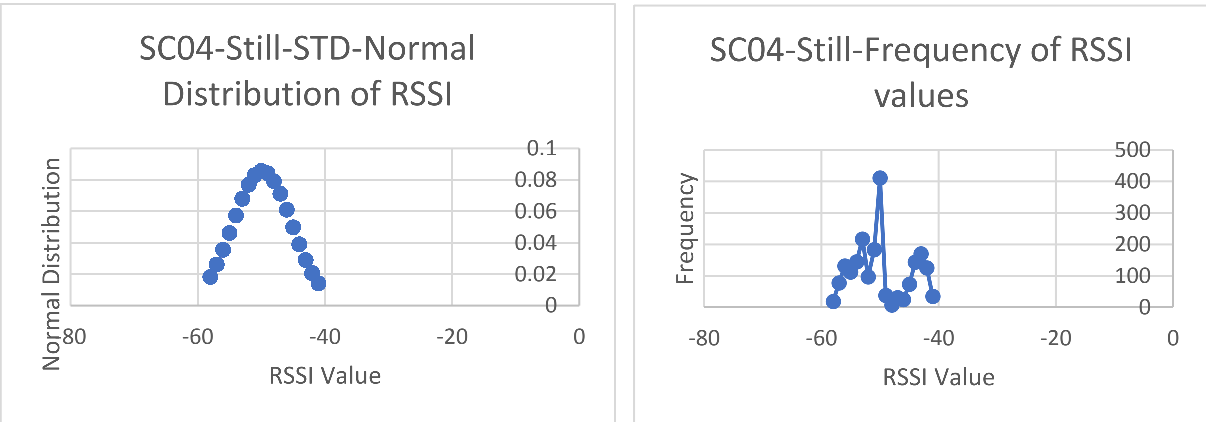


Figure 34 : SC04 Normal Distribution and frequency variation of RSSI Values without movement

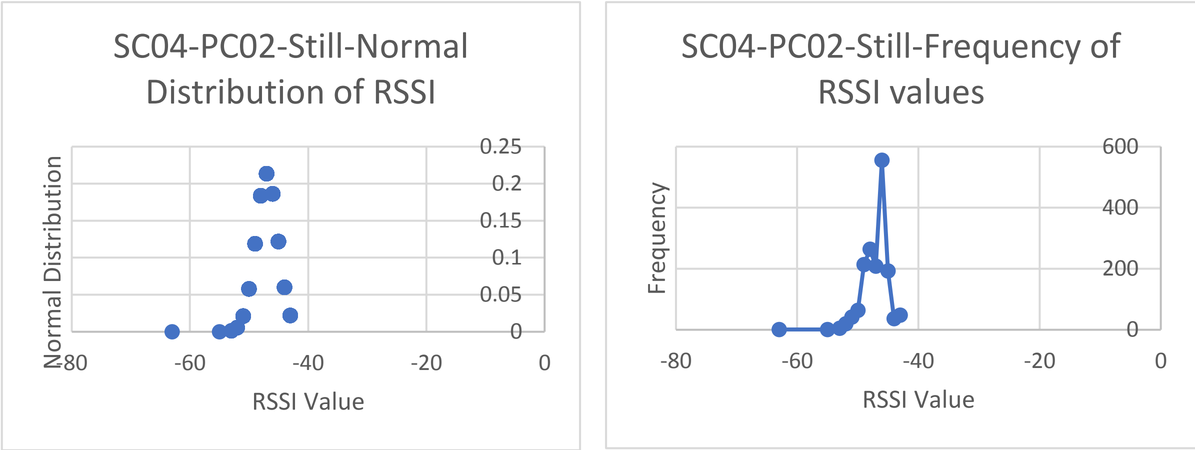


Figure 35 : SC04-Reciever 02 Normal Distribution and frequency variation of RSSI Values without movement

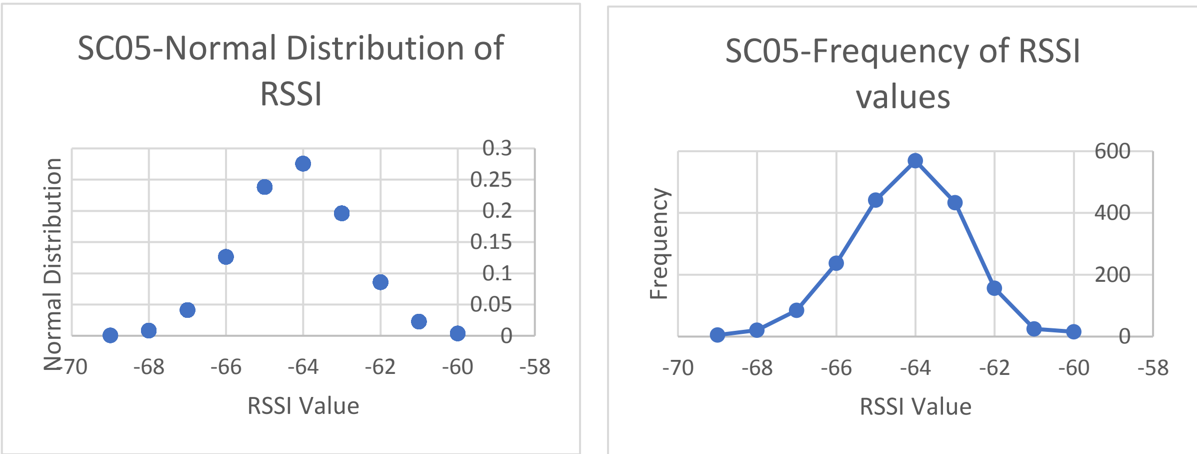


Figure 36 : SC05 Normal Distribution and frequency variation of RSSI value

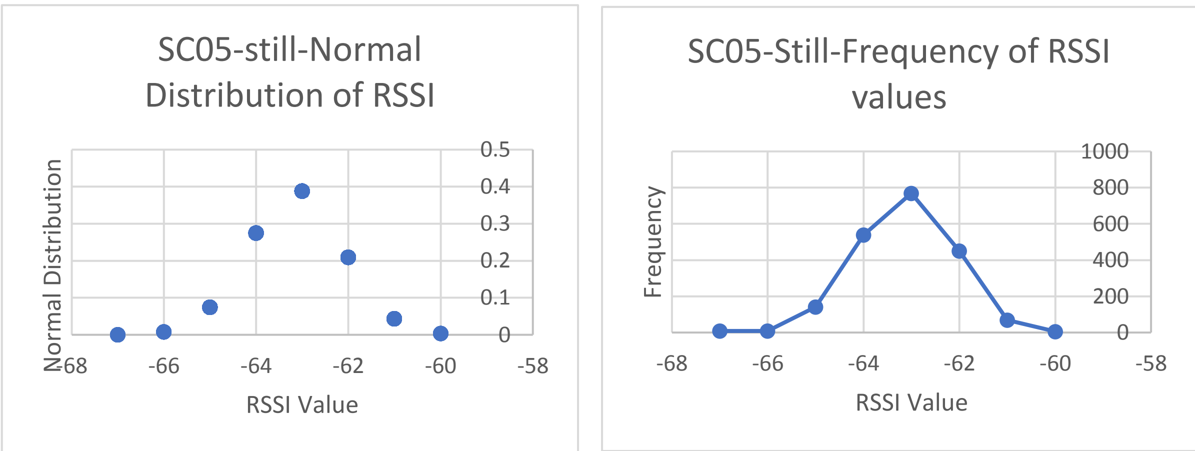


Figure 37 : SC05-Reciever 02 Normal Distribution and frequency variation of RSSI value

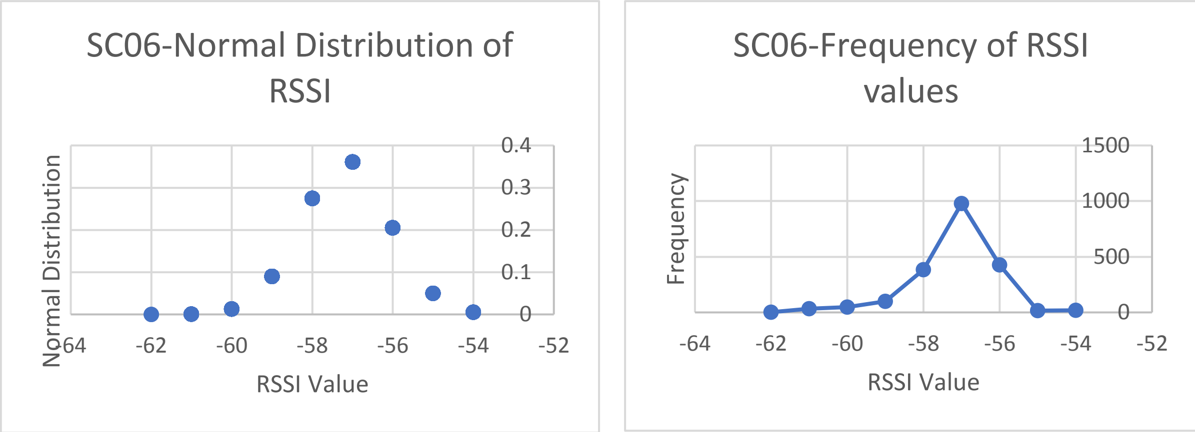


Figure 38 : SC06 Normal Distribution and frequency variation of RSSI value

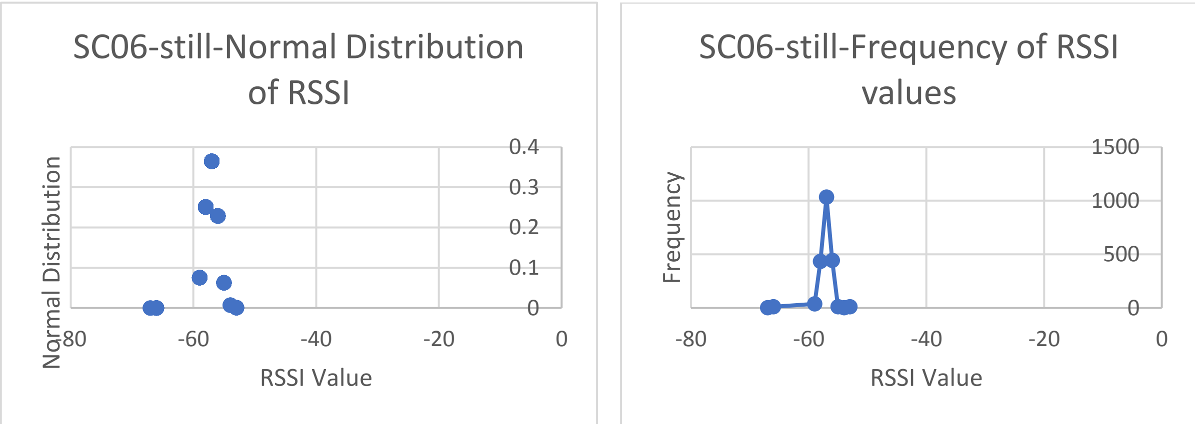


Figure 39 : SC06 Normal Distribution and frequency variation of RSSI Values without movement

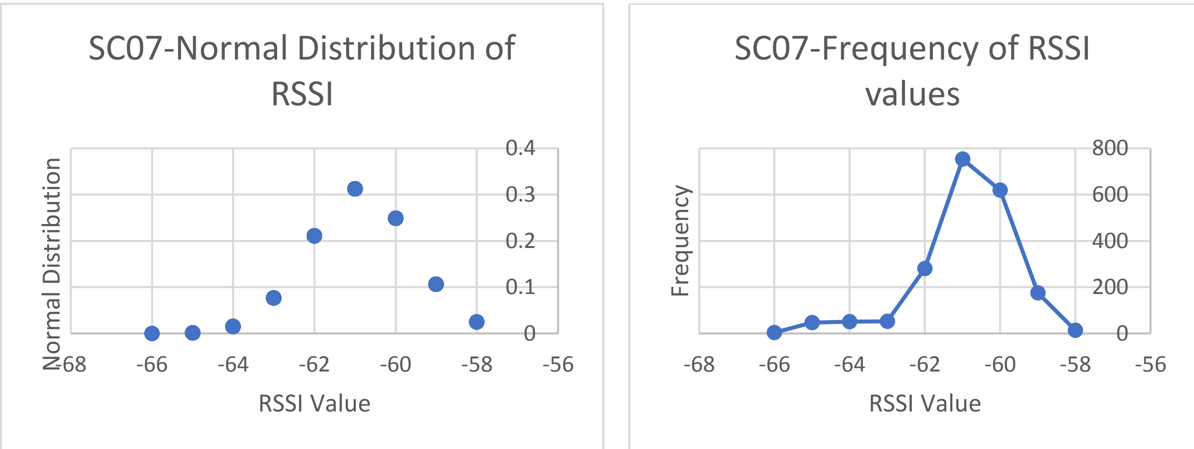


Figure 40 : SC07 Normal Distribution and frequency variation of RSSI value

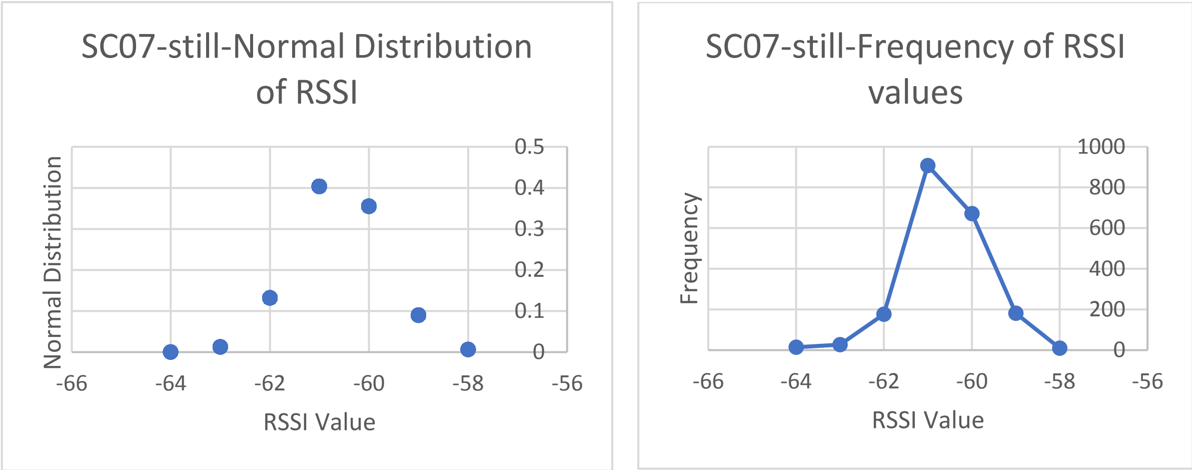


Figure 41 : SC07 Normal Distribution and frequency variation of RSSI Values without movement

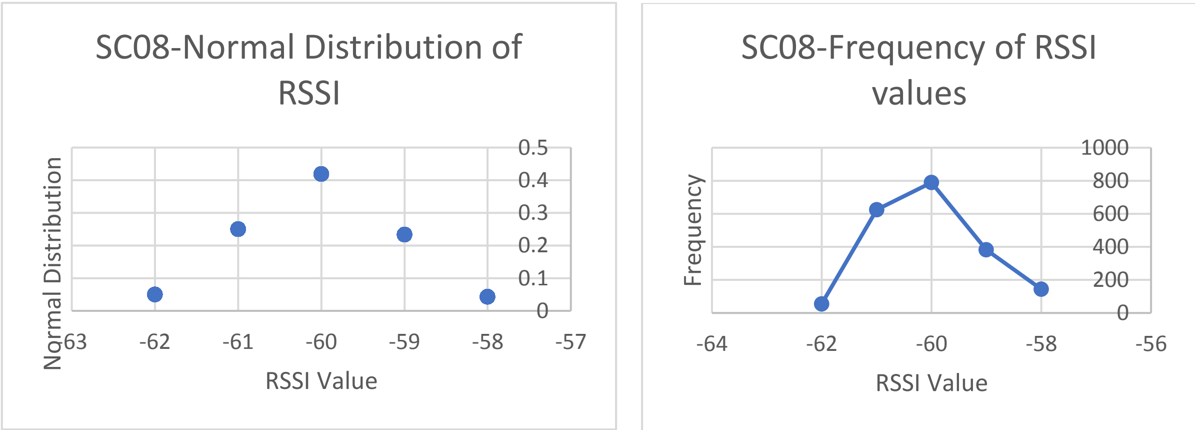


Figure 42 : SC08 Normal Distribution and frequency variation of RSSI value

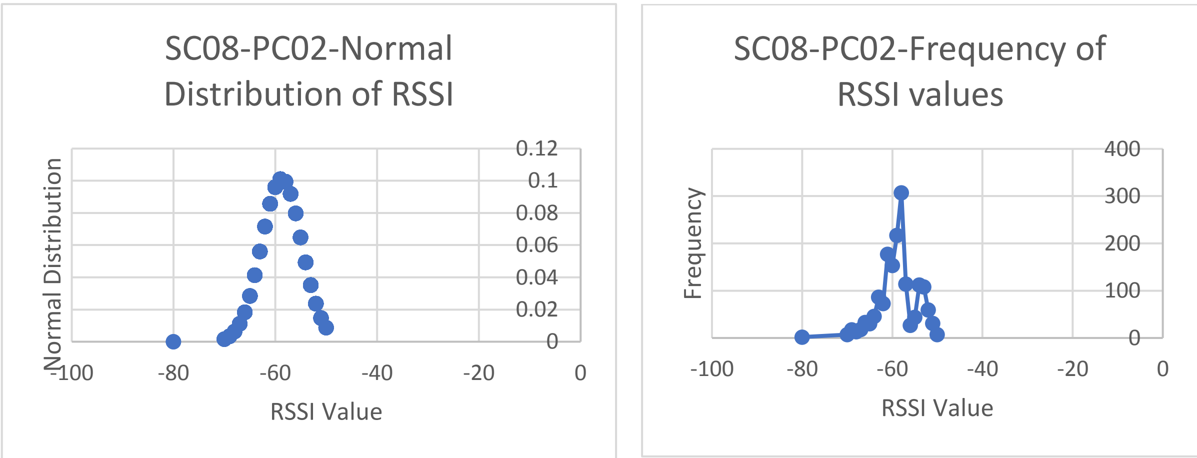


Figure 43 : SC08 -Receiver 02 Normal Distribution and frequency variation of RSSI value

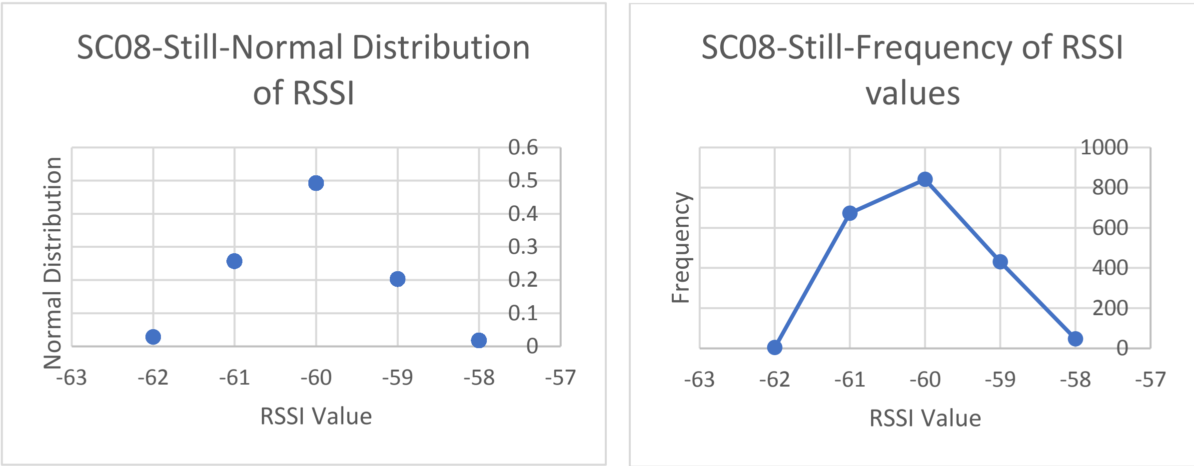


Figure 44 : SC08 Normal Distribution and frequency variation of RSSI Values without movement

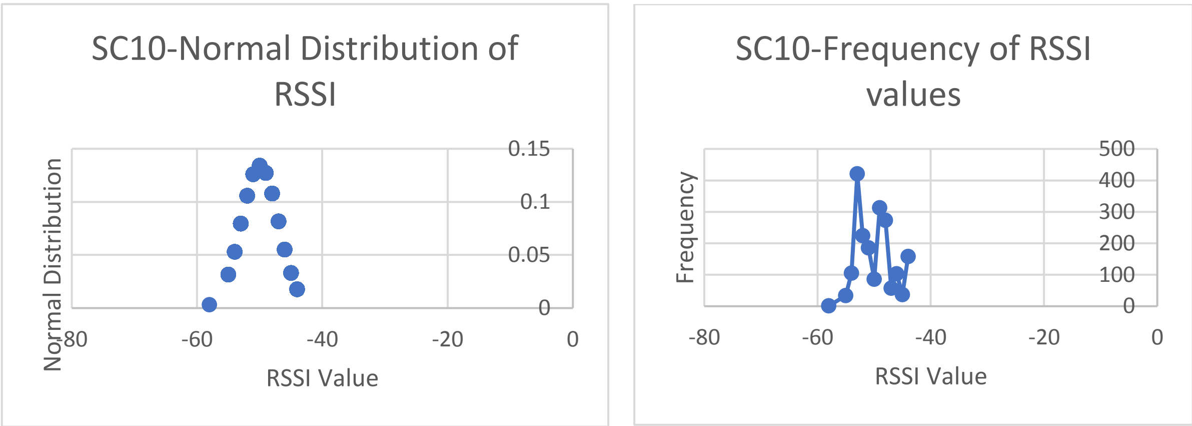


Figure 45 : SC10 Normal Distribution and frequency variation of RSSI value

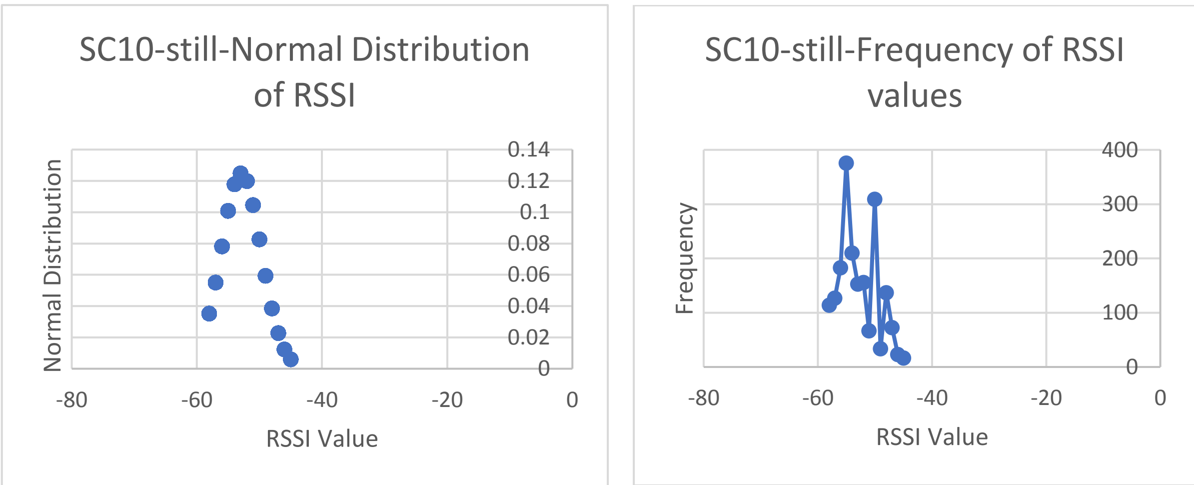


Figure 46 : SC10 Normal Distribution and frequency variation of RSSI Values without movement

In the same time Mean values and the standard deviation values are calculated with respect to each scenaarios. Below table comprise the summery of mean and standard deviation which are calculated for each scenario. For the calculation following formulas are used,

$$s = \sqrt{\frac{\sum_{i=1}^{n} |X_i - \bar{x}|^2}{n}}$$

Figure 47 : Formula for calculate standard deviation

$$Mean = \frac{\sum_{i=1}^{n} x_i}{n}$$

Figure 48 : Formula for average calculation

S – Standard Deviation

X – Element value (RSSI value)

$\bar{x}$- Mean value

n – No of elements

Scenario Name	Mean Value ($\bar{x}$)(dBm)	Standard Deviation (s)
SC01	-60.322	1.565420477
SC01 – without movement	-58.7881	0.942643819
SC02	-60.8781	1.681068071
SC03	-61.3131	0.896885932
SC03 – Reciever 2	-51.6197	1.616753178
SC03 - without movement	-61.097	0.904789199
SC03 - Reciever 2 without movement	-51.8885	1.435184346
SC04	-54.83044125	2.737708
SC04 – Reciever 2	-51.0283	2.242204262
SC04 - without movement	-49.8342	4.654585478
SC04 - Reciever 2 without movement	-46.977	1.869064118
SC05	-64.1983	1.432329976

SC05 – without movement	-63.1411	1.019247194
SC06	-57.1734	1.090532811
SC06 – without movement	-57.0552	1.093316921
SC07	-60.8662	1.268331066
SC07 – without movement	-60.6032	0.895701468
SC08	-60.0315	0.952007824
SC08 – without movement	-60.0771	0.807071758
SC08 – Reciever 2	-58.7246	3.940591214
SC10	-49.96	2.9721455
SC10 – without movement	-52.907	3.199065553

Table 3 : Standard deviation and Mean values for scenario list

The all generated data as graphs and statistical values will be evaluated within the next phase of the chapter. Mainly these values are willing to use for prove the RT methodology is applicable for this testing environment.

4.1.2 SNR based analysis

Within this phase the collected data is analyzed using the Signal to Noise ratio(SNR) to identify "Are there any pattern exists or can be derived from the collected data". Also, if patterns are existing or derived, then going to correlate those patterns with the human movements.

The SNR calculation is based on the following formula,

$$\mathrm{SNR} = \mu/\sigma$$

Where μ is mean value of the signal and σ is the standard deviation of the noise.

The SNR calculation is conducted with use of different variations factors and parameters. Within these each variation, factors and parameters in used are changed purposely to derive different outputs from the analyzed data. The changes done to factors and parameters are listed below,

i. Generate SNR values without any changes

   In this method calculated general SNR value with the use of raw RSSI values collected in the each of scenario.

ii. Generate SNR values with different window sizes

   In this method, RSSI values for each scenario is grouped into different segments with the definition of window size parameter. The window size represents number of elements in a group or a segment. For an example if window size is 10, then each segment has 10 values. If scenario file contains 2000 RSSI values first it takes first 10(1-10) values and calculated SNR value, then take 2-11 RSSI values and generate SNR then it will generate 3-12 values etc.
   Within this analysis, used five different window sizes to check the variations of analyzed data. The used window sizes are 10,20,30,40 and 50.

In this method, we have generated SNR values for different window sizes. Because we were going to derive, are there any relationship or pattern may exist once we group values to different window sizes and calculated SNR values for those groups. With group values, it provides better expression of data rather than using a single value. For an example when we take group averages it provides precise value point than the single value.

For this analysis, python based script (See the Appendix B – SNR calculation script) are used to calculate SNR values and the outputs are generated as graphs using PHP scripts and HTML. The outputs are represented as follows,

Scenario Name	*SNR value*
SC01	-38.53406
SC01 – without movement	-62.36511
SC02	-36.21393
SC03	-68.36217

SC03 – Reciever 2	-31.92802
SC03 - without movement	-67.526209
SC03 - Reciever 2 without movement	-36.15458
SC04	-20.02786
SC04 – Reciever 2	-22.75808
SC04 - without movement	-10.70646
SC04 - Reciever 2 without movement	-25.13395
SC05	-44.82088
SC05 – without movement	-61.94879
SC06	-52.42703
SC06 – without movement	-52.18544
SC07	-47.98923
SC07 – without movement	-67.66006
SC08	-63.05783
SC08 – without movement	-74.43838
SC08 – Reciever 2	-14.9025
SC10	-16.80939
SC10 – without movement	-16.53827

Table 4 : SNR values for each scenario without any parameter change

Graphical outputs using the graphs with the different window sizes are can be listed as following graph [Figure 49]. Here contains some part of graphs and all the graphs are listed in Appendix D.

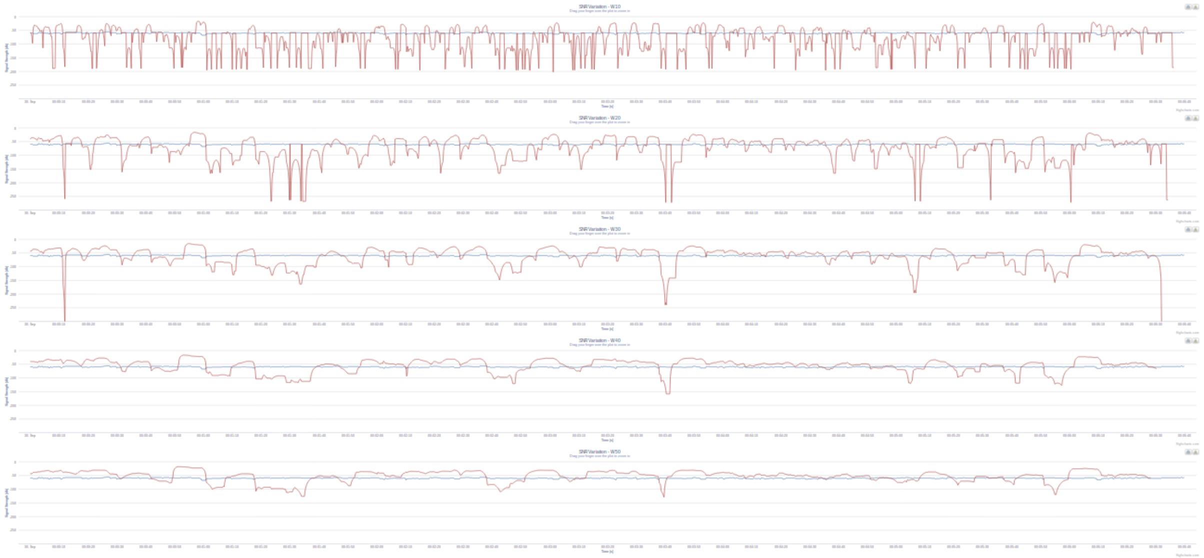


Figure 49 : This figure shows the scenario SC01 sample graph for SNR value variation with different window sizes

4.1.3 Patwari's Algorithm based Analysis

Two special scenarios are developed for applying the patwari's mathematical model to the testing environment for generate the radio tomographic image regards to the object localization. For each scenario used special parameters and environment setup for optimize the accuracy level of the generated images.

As the first step, gathered values from each receiver without any object movement inside the room. This measurement taken as the calibration point of testbed environment. In the next phase human is moved inside the room and collect the RSSI values with the human object. The RT image will be constructed by making comparison with two different value sets which are collected by the early steps.

Within this process, assumed all the noises for the both steps are constant during the data collection period and by doing comparison with each other data sets, the noises are become neutralized or counteract.

For RT image generation, used Octave language based code (See appendix B) to implement the patwari's mathematical model.

4.1.3.1 Special scenario 01

The test bed is prepared with the one transmitter and four receivers. The transmitter and the receivers are located as the following diagram,

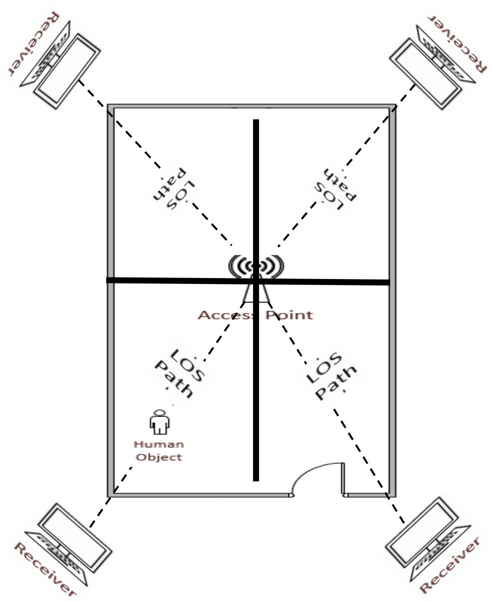
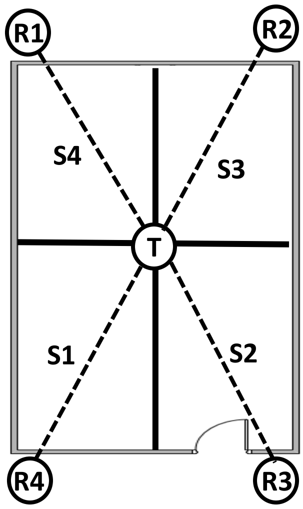


Figure 50 : Special scenario01 setup for RT image generation

Assume transmitter is T, received values are R1, R2, R3, R4 and Areas are S1, S2, S3, S4. We can derive the following formulas to obtain the interaction between of each parameter with others.



Topology A

For Topology A:

If the Links values are L1, L2, L3 and L4,

L1 = R1

L2 = R2

L3 = R3

L4 = R4

For the empty data collection without human object, if voxels values are eV1, eV2, eV3 and eV4,

A = [eV1, eV2, eV3, eV4]

In the next step if the voxels values are V1, V2, V3 and V4,

B = [V1, V2, V3, V4]

The attenuation of the two phases can be derived by using Mdiff value. Mdiff value shows difference of attenuation in voxels A,B.

Mdiff = A-B;

The output is represented the signal attenuation in voxels which is caused by the human object. With the use of above formulas, following RT images are generated. The faded color levels are indicated the RSSI value fluctuations. That means any object has located inside that voxel area.

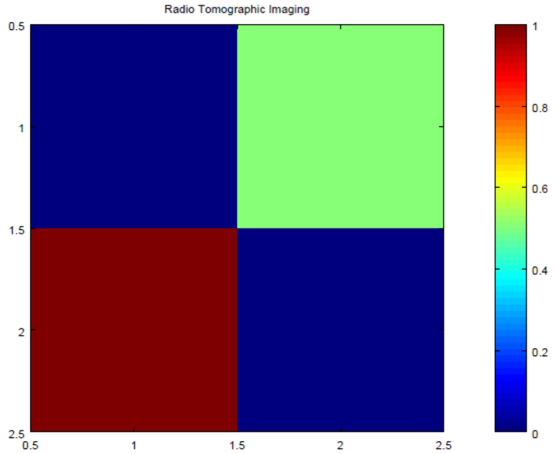


Figure 51 : RT image for Human object located in the S1 Area

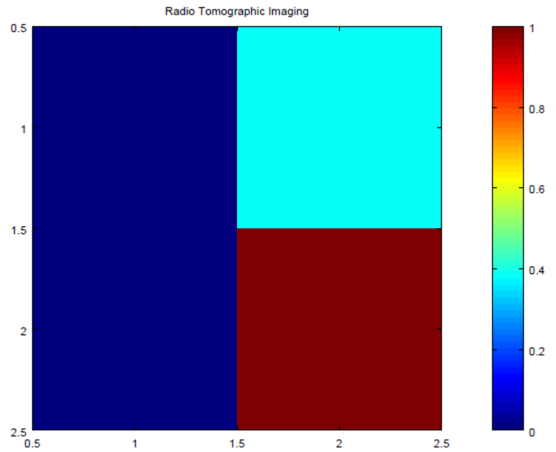


Figure 52 : RT image for human object located in S2 area

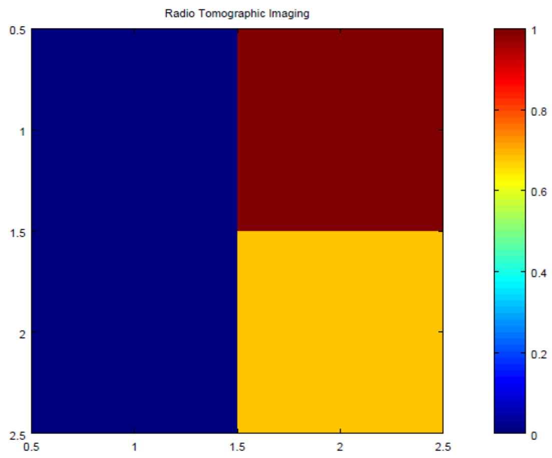


Figure 53 : RT image for human object located in S3 area

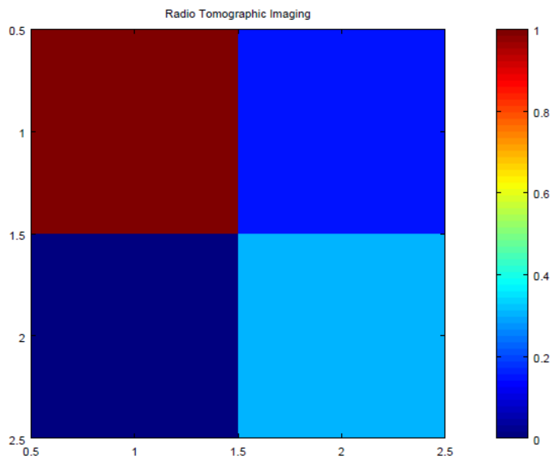


Figure 54 : RT image for human object located in S4 area

Here the color levels are varying from the blue to red. Red shows the maximum signal fluctuation in the Links. In theoretically, the all other voxels rather than the object located one should in same color level. But in the practical environment, there are noises and various other effects on the signal links. So, that will change the signals attenuations in links and cause to vary the colors in the voxels.

Regards to the figure 51, human is in the S1 area and in the next phase he moves to the S2 area. That signal attenuation is clearly identified in the figure 52. In figure 53 human object is moved into the S3 voxel area. Finally, the human moved to the S4 voxel area and it represented in the figure 54.

4.1.3.2 Special scenario 02

In this scenario access point(AP) and receiver 02 transmit the wireless signals. Also, R1, R2, R4 receivers are captured the data. Here A1, A2, A3 and A4 is the object maps which are already known as voxels.

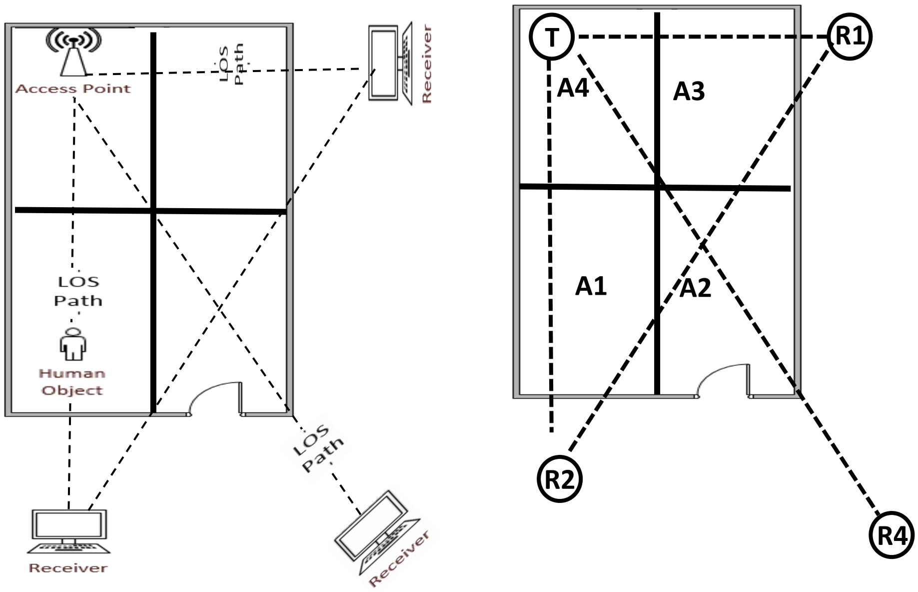


Figure 55 : Special scenario02 setup for RT image generation

According to the patwari's mathematical model, Single line formula is applied in this test scenario to generate the RT image. The required formulas can be represented as the following equations,

Within this calculation initial calibration voxels values are taken as A and In the next phase it is taken as B,

First use the RSSI data which are taken by without human object (for empty room) to calculate voxels values eV1, eV2, eV3, eV4

As the next step generate average values for the four links eL1, eL2, eL3 and eL4,

eL1 = X_1;
eL2 = X_2;
eL3 = X_3;
eL4 = X_4;

Calculate the attenuation in voxels using single line mathematical model,

eV1 = eL4 -eL3;
eV2 = eL1 - eL4 + eL3;
eV3 = eL3;
eV4 = eL2 - eL4 + eL3;

A = [eV1, eV2; eV4, eV3];

In the next level, we take the RSSI values which are collected with human object inside the room,

If the average values for four links are L1, L2, L3 and L4. Then,

L1 = Y_1;
L2 = Y_2;
L3 = Y_3;
L4 = Y_4;

Calculate the attenuation in voxels using single line mathematical model,

V1 = L4 - L3;
V2 = L1 - L4 + L3;
V3 = L3;
V4 = L2 - L4 + L3;

B = [V1, V2; V4, V3];

Finally take the differentiation of the attenuation by using,

Mdiff = A-B;

As a result of above equations, the following RT images are generated. In each phase, human object is moved from one voxel to another (S1 to S4)[Figure 56] to check the accuracy level of generated images.

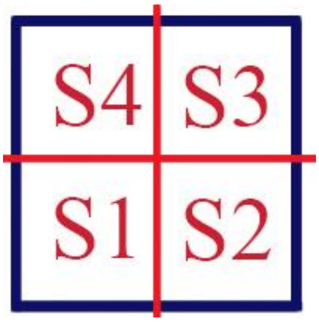


Figure 56 : Object map for the test environment

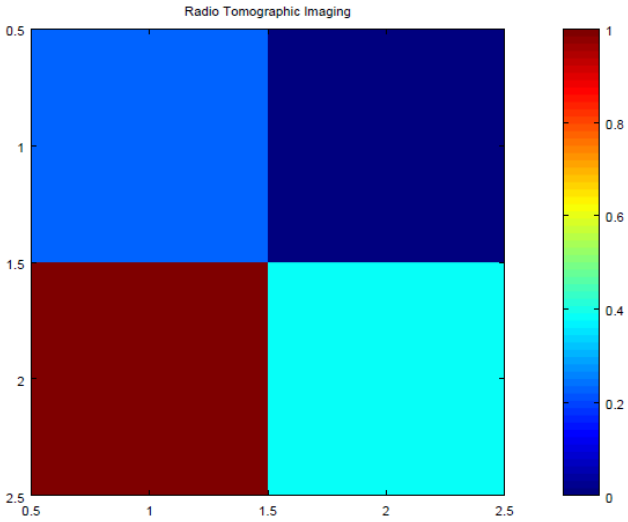


Figure 57 : RT image for human object located in S1 area

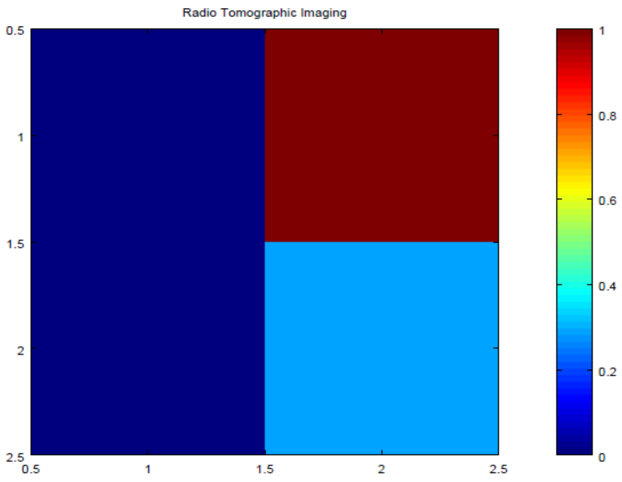


Figure 58 : RT image for human object located in S2 area

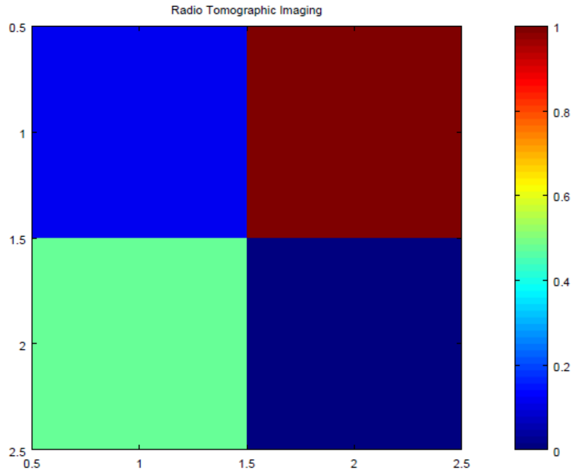


Figure 59 : RT image for human object located in S3 area

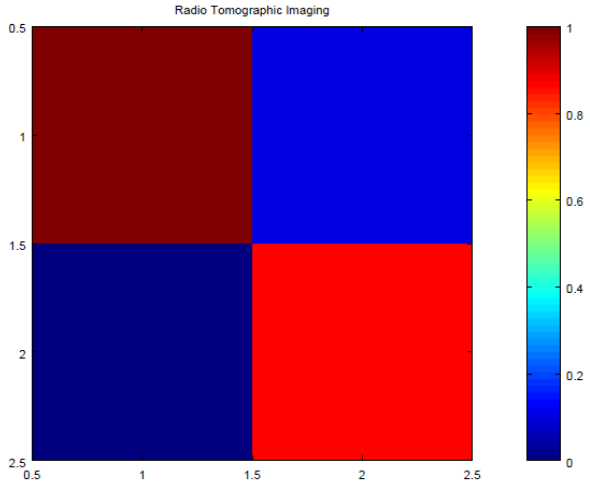


Figure 60 : RT image for human object located in S4 area

In the generated RT images, voxels colors are varying from blue to Red. In figure 57, it represents the color changes in the S1 voxel because human object is in the S1 area and it causes the signal attenuation in S1 voxel. In figure 58 human object is in S2 voxel. But it shows the variations in S3 voxel because the links are going through the side of S2. So, it doesn't create much attention in S2 voxel. But in Figure 59 and 60 human object is moved from S3 to S4 voxel and it clearly identify the signals attenuation in both S3 and S4 voxels.

4.2 Evaluation

With use of above Standard deviation based, SNR based and Patwari's algorithm based methodologies, able to resolve my research questions in convenient way. First Standard deviation based methodology is used to prove radio tomographic concept is acceptable for my test environment. In here, used graphical method and the statistical method to derive the answers form the collected RSSI values. In graphical technique, use the normal distribution graphs to check the variation of RSSI values due to the passive Wi-Fi tomography. In figure 32, 35, 37, 38 and 39, can clearly identify the variation of the signals using normal distribution graphs. Within the statistical technique, mainly used the standard deviation values to identify the variation of signal level attenuation. The following table provide some of the figures that indicates standard deviation values are increases when objects are move inside the room.

Scenario	Standard deviation value (with object movement)	Standard deviation value (Without object movement)
SC01	1.565420477	0.942643819
SC03 – Reciever 2	1.616753178	1.435184346
SC04 – Reciever 2	2.242204262	1.869064118
SC05	1.432329976	1.019247194

Table 5 : Summarized sample data shows Standard deviation values are increases with the Object movement

No of scenarios conducted	12
No of scenarios conducted (with two special cases designed for RT image generation)	14
No of scenarios directly express increment of standard deviation values due to human objects	8
No of scenarios directly express increment of standard deviation values due to human objects (with two special cases designed for RT image generation)	10

Table 6 : This table present summarization values of Standard deviation method which are useful to derive the accuracy levels

By using these techniques can be proved radio tomography concept are valid for my current testing environment with the accuracy of 66.66% - 71.4%. This is resolved the first part of the research question.

In the next step, used SNR based methodology to prove can signal variation able to detect the object movements inside the room. With regards to signals to noise ratio values what we have generated from the collected RSSI data, shows there is a significant change in SNR value when there are movements in inside the room. Some summarized sample data figures can be tabulate as follows,

Scenario Name	*SNR Value (With movement inside the room)*	*SNR Value (Without movement inside the room)*
SC01	-38.53406	-62.36511

SC03 – Reciever 2	-31.92802	-36.15458
SC04 – Reciever 2	-22.75808	-25.13395
SC05	-44.82088	-61.94879
SC07	-47.98923	-67.66006

Table 7 : Summarized data using SNR calculation when the objects are moving inside the room

No of scenarios conducted	12
No of scenarios conducted (with two special cases designed for RT image generation)	14
No of scenarios successfully show reduction of SNR values due to human objects	7
No of scenarios successfully show reduction of SNR values due to human objects (with two special cases designed for RT image generation)	9

Table 8 : This table present summarization values of SNR based method which are useful to derive the accuracy levels

With the comparison of the SNR values in the table can be identified SNR value is decreased when there is a movement in inside the room. Using this technique, can be identified the movements in inside a room with the accuracy level in range of 58% to 64%. But the limitation is, can only identify the movement. We cannot specify any parameters likes type of movement, directions etc. by looking at changes in SNR values.

As the final stage of data evaluation, used patwari's mathematical model for generate tomographic image of inside the testbed. This is helped to prove the object localization using the passive Wi-Fi tomography. For this, we have arranged two special scenarios to gather data. Also, we have used single line model for check the signal attenuation and generate the RT image regard to the signal variation. Each image is comprised with the four voxels and each voxel is 10ft long and 6.5ft Hight. Each scenario creates four links throughout the environment and within the data collection, that four links values are measured.

When we consider the 1st special scenario, it was generated four RT images and all the images are providing positive result which shows human object locations correctly. Therefore 1st scenario achieved 100% of accuracy. For the second one, also generated four RT images and one image [figure 58] represent false data of human location. Therefore, this scenario accuracy level reduced to 75%

As overall result, with using this technique we could locate the human object within the test environment with the 75% - 87% average accuracy. Also by using the RT image, we can identify where the object is located and in which quarter. Instead of that we derived that the scenario with the transmitter in center point of the room produced the RT image with high accuracy.

As mentioned early, the research questions can be answered with use of above outputs with some extend. There are some limitations created when deriving the outputs. Also, some output values are outliers because of various reasons like noises, environmental changes etc. But as a whole the expected results are generated through this research.

Chapter 05

CONCLUSION

This is the last chapter of my dissertation and this chapter is contained comprehensive summery of the work what has done in the previous chapters. Also, this chapter is express the decisions which has taken by the data analysis and evaluation phases. Furthermore, describes what can be done in the future with the use of this research.

5.1 Contribution

Radio tomography is the one of trending field in the todays world. With the innovations of technology, the world become connected through the wireless networks. Mainly Wi-Fi technology creates revolution in the wireless industry. My research is combined both Wi-Fi and the radio tomography concepts and try to open the concerns in new area which is information privacy field. Within my research tried to conduct a case study on privacy implications due to passive wi-fi tomography.

As a starting phase, need to implement my testbed environment and collect the initial data for answer the research question of "Is my testbed environment valid for Radio tomographic concepts?". To answer this question, used two techniques which are related to the statistical model and graphic model. In this process collected RSSI values are analyzed by using the standard deviation function and produce the normal distribution graphs for analyzed data. The final output of this phase produce positive answer but it creates some unexpected results and limitations for further use of data.

In the next phase of this research, conduct SNR based methodology to answer the simple question of "Can we identify the movements in inside the room?". According to the analyzed values using the SNR function, abled to answer the question with higher accuracy level but also the same issue is arrived. It created limitations like it just identify the movement but not any other parameters like type of the movements, directions etc.

As the final stage, used patwari's mathematical model for localize the objects in inside of the test environment. This technique is solved the question of "Can locate the human objects in inside testbed?" with 75% of high accuracy level.

This research is solved the most parts of the identified research questions and some parts are need to be developed in future as the extension of this work.

5.2 Challenges

i. Unavoidable Noise/ Multipath issue

The main challenge for this research is the Noise due to the environment. My test environment located in the indoor environment and it is heavily surrounded with other wireless networks. Also, the environment is created with the use of claddings and glasses. So, it creates more multipath for the wireless waves. Therefore, some scenario outputs are generated abnormal results rather than the expected.

ii. Arrangement of devices

Within the data collection, needed to change the environment and the devices locations according to the scenario. But it was created extra overhead because of the lack of space in the test environment and objects which are already in that location.

iii. Require high computing resources

In the evaluation stage needed to generate radio tomographic image for identify the human objects in the environment. But this process needs more computation power. Because the generation code is written in octave language and it needed to execute more mathematical models during the image generation with respected to collected RSSI data. Also, this process taken considerable time frame for image generation. Therefore, if need to change any simple parameter for testing, it required to regenerate the image from the scratch and that take more time than we expected.

5.3 Future Work

My research can be used as the base model for future studies and researches in information security and privacy area. These are some extends which can be proposed as the future works,

i. Audit of environmental factors effect for Passive Wireless Tomography [22]

   Within this research, assumed all the environmental factors are constant during the data collection. But in the real world this should be vary and it will affect the collected data. These are some factors can be affected to the collected data in real scenarios,

   - Temperature/Humidity
   - Wall thickness
   - Object sizes and moving speed, directions etc.

ii. Increase the accuracy level of the generated RT image

   My research only generated basic model of tomographic image for the testbed environment and it can be developed in future through several improvements. Mainly need to increase the accuracy level of RT image by increasing the no of receivers and links.

iii. Identify the human movements with high accuracy

   Within this study, abled to identify the human objects locations within the indoor environment. But need more concentration on accuracy. Furthermore, need to identify the movement within the wireless environment.

iv. Real-time human identification system

   With the use of this base model can be develop real-time human object movement detection system by using the wireless tomography methodology. It will use the RSSI values and produce the presence of humans within the wireless perimeter.

v. Framework for privacy breaches and implications

   As the next step of this research can be produce a new framework for audit the privacy implications which is caused by the passive Wi-Fi tomography techniques. Within this framework can specify what areas need concerns and how these privacy implications can be reduced or mitigated during wireless implementations.

REFERENCES

[1] "Wireless X-ray detector for a digital radiography system with remote X-ray event detection," 2006.

[2] "Magnetic resonance devices suitable for both tracking and imaging," 1995.

[3] T. Z. Kazem Sohraby, Daniel Minoli, Wireless Sensor Networks: Technology, Protocols, and Applications - Kazem Sohraby, Daniel Minoli, Taieb Znati - Google Books. .

[4] R. Want, "An Introduction to RFID Technology," IEEE Pervasive Comput., vol. 5, no. 1, pp. 25–33, Jan. 2006.

[5] E. Ferro and F. Potorti, "Bluetooth and wi-fi wireless protocols: a survey and a comparison," IEEE Wirel. Commun., vol. 12, no. 1, pp. 12–26, Feb. 2005.

[6] M. Chan, D. Estève, C. Escriba, and E. Campo, "A review of smart homes—Present state and future challenges," Comput. Methods Programs Biomed., vol. 91, no. 1, pp. 55–81, 2008.

[7] J. Wilson and N. Patwari, "Radio Tomographic Imaging with Wirless Networks," vol. 9, no. 5, pp. 621–632, 2008.

[8] M. Seifeldin and M. Youssef, "A deterministic large-scale device-free passive localization system for wireless environments," in Proceedings of the 3rd International Conference on PErvasive Technologies Related to Assistive Environments - PETRA '10, 2010, p. 1.

[9] Y. Zhao, N. Patwari, J. M. Phillips, and S. Venkatasubramanian, "Radio tomographic imaging and tracking of stationary and moving people via kernel distance," in Proceedings of the 12th international conference on Information processing in sensor networks - IPSN '13, 2013, p. 229.

[10] J. M. Fromholz, "The European Union Data Privacy Directive," Berkeley Technol. Law J., vol. 15, no. 1, pp. 461–484, 2000.

[11] F. Soldovieri and G. Gennarelli, "Exploitation of Ubiquitous Wi-Fi Devices as Building Blocks for Improvised Motion Detection Systems," Sensors (Basel)., vol. 16, no. 3, p. 307, Mar. 2016.

[12] A. Goldsmith, "Wireless Communications," Wirel. Commun., p. 250, 2005.

[13] A. Goldsmith, Wireless Communications. Cambridge University Press, 2005.

[14] R. van Nee and R. Prasad, OFDM for Wireless Multimedia Communications, 1st ed. Norwood, MA, USA: Artech House, Inc., 2000.

[15] J. Sirimanne, "Privacy and Security Implications on Wireless (Wi-Fi) Tomography." 2015.

[16] J. Jayasooriya, "Investigation of Privacy Violations In Wi-Fi Band Using Software Defined Radio," no. December, 2015.

[17] Q. Pu, S. Jiang, and S. Gollakota, "Whole-home gesture recognition using wireless signals (demo)," Proc. ACM SIGCOMM 2013 Conf. SIGCOMM - SIGCOMM '13, p. 485, 2013.

[18] P. B. and V. N. Padmanabhan, “RADAR: An in-building RF based user location and tracking system,” Proc. IEEE INFOCOM 2000. Conf. Comput. Commun. Ninet. Annu. Jt. Conf. IEEE Comput. Commun. Soc. (Cat. No.00CH37064), vol. 2, no. c, pp. 775–784, 2000.

[19] J. Ryckaert, C. Desset, A. Fort, M. Badaroglu, V. De Heyn, P. Wambacq, G. Van der Plas, S. Donnay, B. Van Poucke, and B. Gyselinckx, “Ultra-wide-band transmitter for low-power wireless body area networks: design and evaluation,” IEEE Trans. Circuits Syst. I Regul. Pap., vol. 52, no. 12, pp. 2515–2525, Dec. 2005.

[20] “Project Soli.” [Online]. Available: https://atap.google.com/soli/.

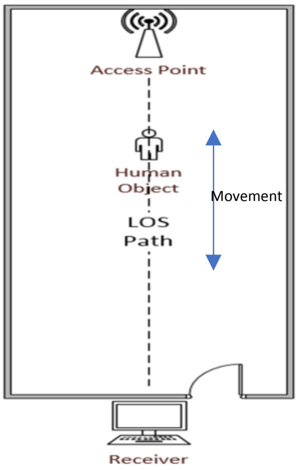
[21] V. Navda, A. Kashyap, and S. R. Das, “Design and Evaluation of iMesh: An Infrastructure-Mode Wireless Mesh Network,” in Sixth IEEE International Symposium on a World of Wireless Mobile and Multimedia Networks, pp. 164–170.

[22] Otero, J., Yalamanchili, P. and Braun, H. (2010). High Performance Wireless Networking and Weather. 1st ed. [ebook] Available at: http://hpwren.ucsd.edu/info/images/weather.pdf.

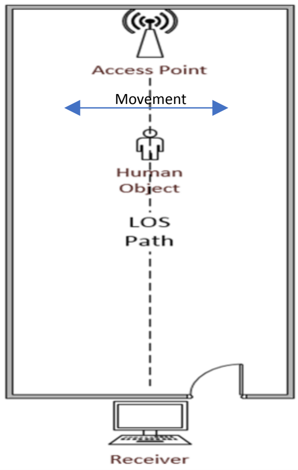
[23] "Number of public hotspots worldwide 2009-2015," The Statistics Portal, [Online]. Available: https://www.statista.com/statistics/218596/global-number-of-public-hotspots-since-2009/.

APPENDICES

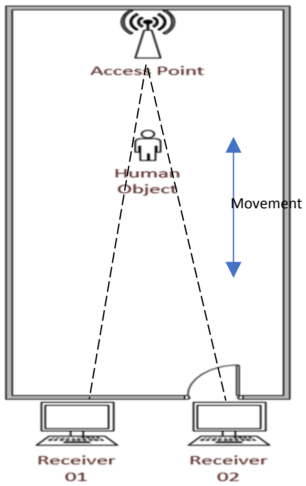
Appendix A - Scenario list



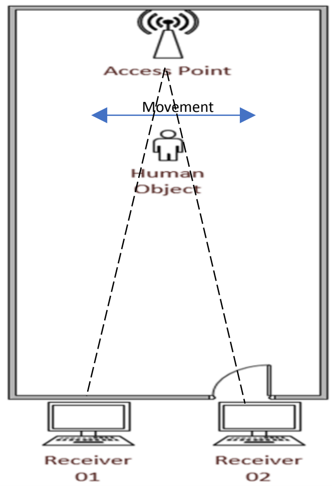
Scenario: SC01



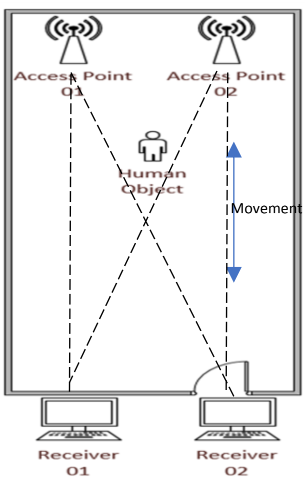
Scenario: SC02



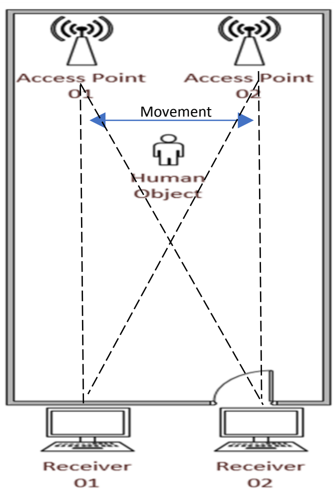
Scenario: SC03



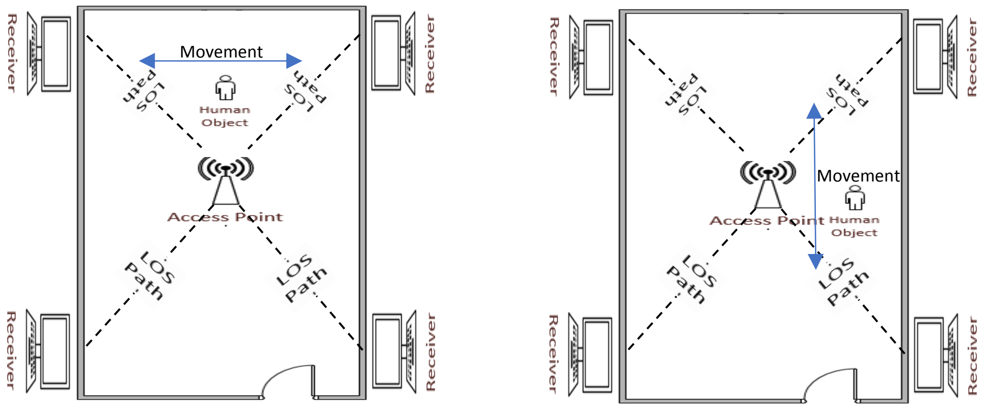
Scenario: SC04



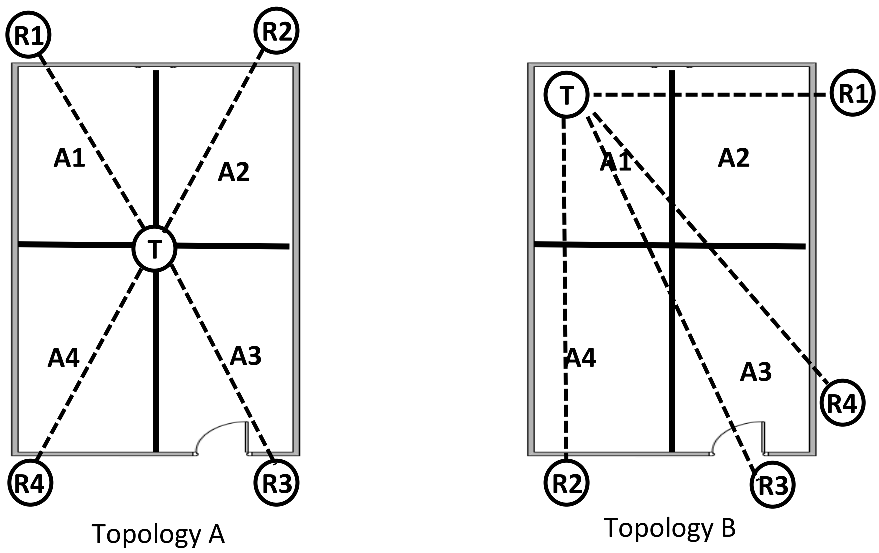
Scenario: SC05



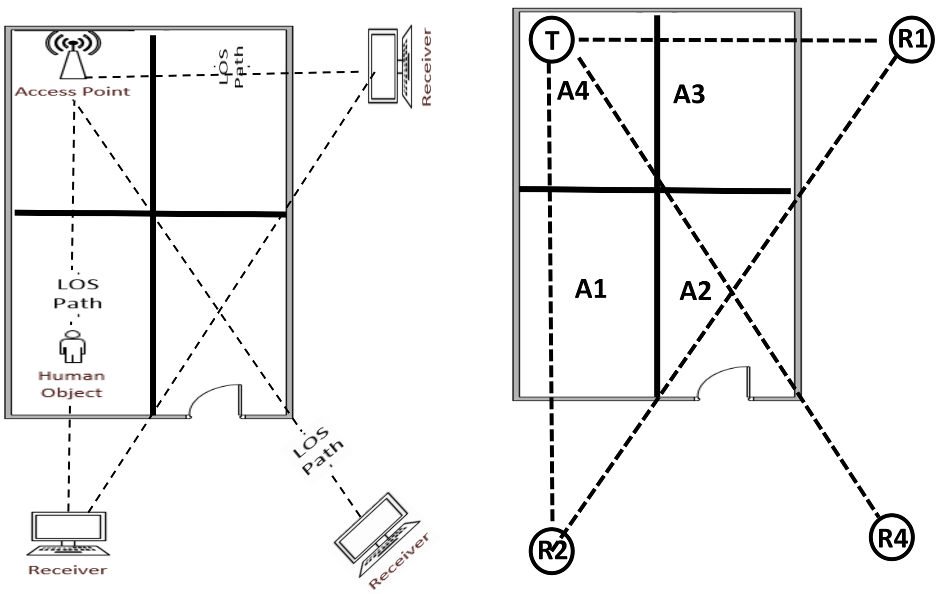
Scenario: SC06



Scenario: SC010



Special Scenario: SC01



Special Scenario: SC02

Appendix B - Data Collection Python script

i. Data collecting python script

```
#!/usr/bin/python
import matplotlib.pyplot as plt
import time
import random
from collections import deque
import numpy as np
import os

a = []

def read_wifi():
    while True:
        f=os.popen('sudo iwconfig wlan0 | grep -e "Signal level"')
        line = f.read()
        splitted_line = line.split()
        level = splitted_line[3].split('=')
        print level[1]
        val = level[1]
        yield val
        time.sleep(0.1)

a1 = deque([0]*100)
ax = plt.axes(xlim=(0, 100), ylim=(0, 10))
d = read_wifi()

line, = plt.plot(a1)
plt.ion()
plt.ylim([-90,-20])
plt.show()
```

```
f = open('data/sc04', 'w')

for i in range(0,10000):
        a1.appendleft(next(d))
        datatoplot = a1.pop()
        line.set_ydata(a1)
        plt.draw()
        print a1[0]
        f.write(a1[0]+'\n')
        i += 1
        time.sleep(0.1)
        plt.pause(0.0001)

f.close()
```

ii. SNR Calculation script

```
#!/usr/bin/python
from __future__ import division
from math import sqrt
import sys

flname = sys.argv[1]
wSize = int(sys.argv[2])

def readVal():
        with open("data/"+flname) as f:
                a = f.read().splitlines()


        f = open('SNR/'+flname+'-SNR', 'w')


        for i in range(len(a)-(wSize+5)):
                c = []
```

```
            for j in range(wSize):
                c.append(a[i+j])

            f.write(repr(snrVal(c))+"\n")

def meanVal(lst):
        """calculates mean"""
        sum = 0
        for i in range(len(lst)):
                sum += int(lst[i])
        return (sum / len(lst))

def stdVal(lst):
    """calculates standard deviation"""
    sum = 0
    mn = meanVal(lst)
    for i in range(len(lst)):
        sum += pow((int(lst[i])-mn),2)
    sq = sqrt(sum/(len(lst)-1))
    return sq

def snrVal(lst):
    """calculates standard deviation"""
    m = meanVal(lst)
    sd = stdVal(lst)
    if sd == 0:
        sd = 1
    return (m/sd)


readVal()
```

iii. RT image generate script : ImageGen.m

```
A = [8, 18; 3, 5];
B = [19,20; 4,8];

disp(A);
disp(B);
Mdiff = A-B;
Mdiff= abs(Mdiff)
minMD = min(min(Mdiff))
maxMD = max(max(Mdiff))
rangeMD= maxMD - minMD

M1= [((Mdiff(1,1)- minMD).*100)./rangeMD, ((Mdiff(1,2)-
minMD).*100)./rangeMD; ((Mdiff(2,1)- minMD).*100)./rangeMD , ((Mdiff(2,2)-
minMD).*100)./rangeMD]

%Generate the image
image(M1)
colorbar
title('Radio Tomographic Imaging');
```

Appendix C - Graphical output of collected RSSI Data

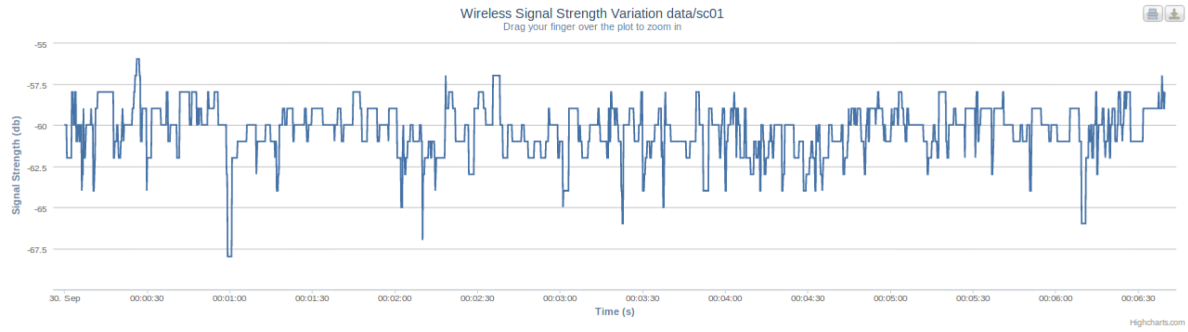


Figure 61 : Appendix C - RSSI data graphical output for SC01

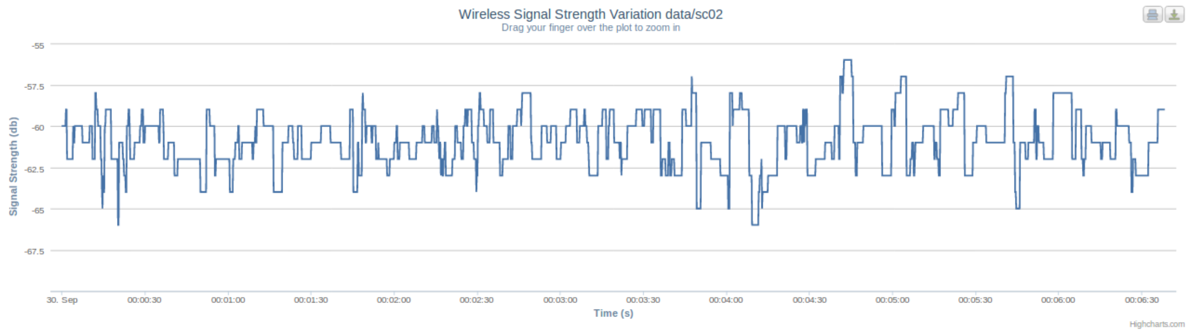


Figure 62 : Appendix C - RSSI data graphical output for SC02

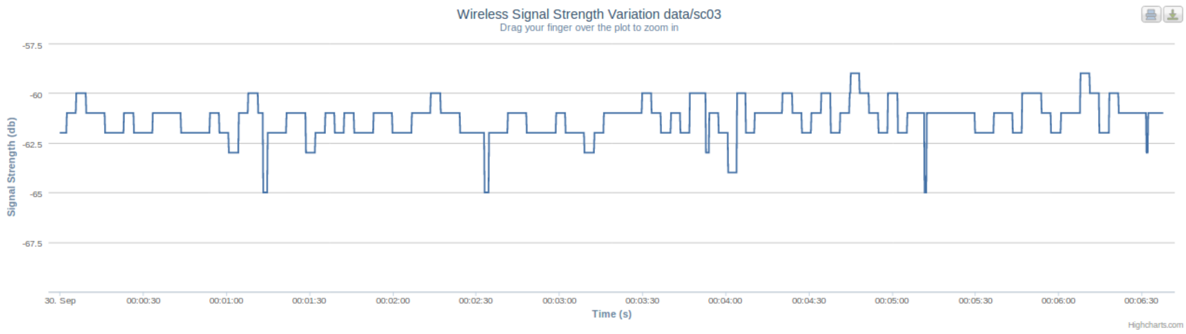


Figure 63 : Appendix C - RSSI data graphical output for SC03

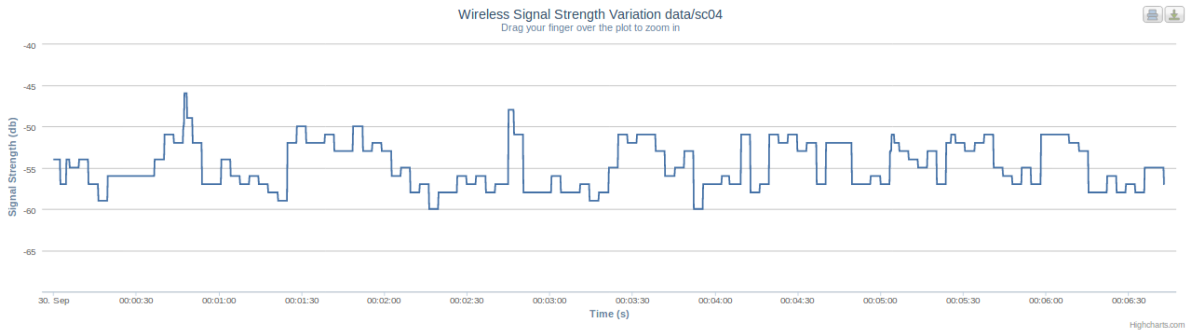


Figure 64 : Appendix C - RSSI data graphical output for SC04

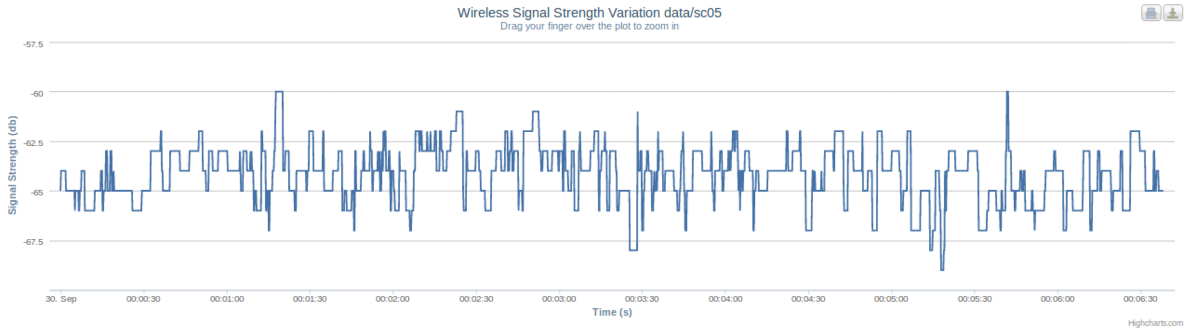


Figure 65 : Appendix C - RSSI data graphical output for SC05

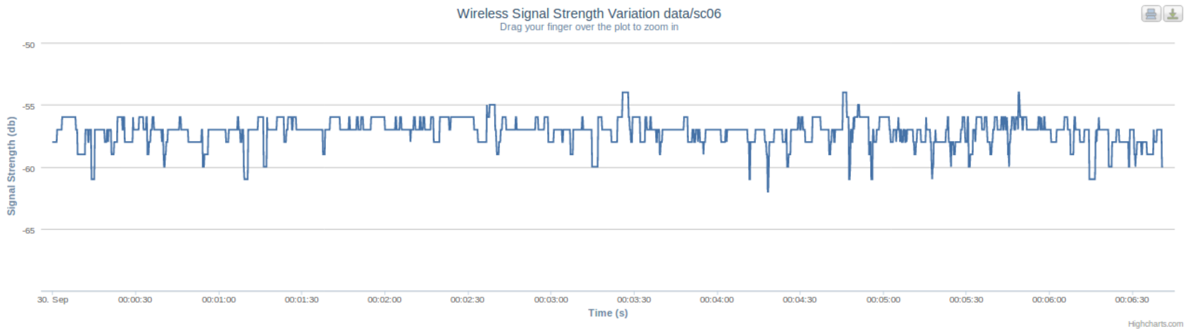


Figure 66 : Appendix C - RSSI data graphical output for SC06

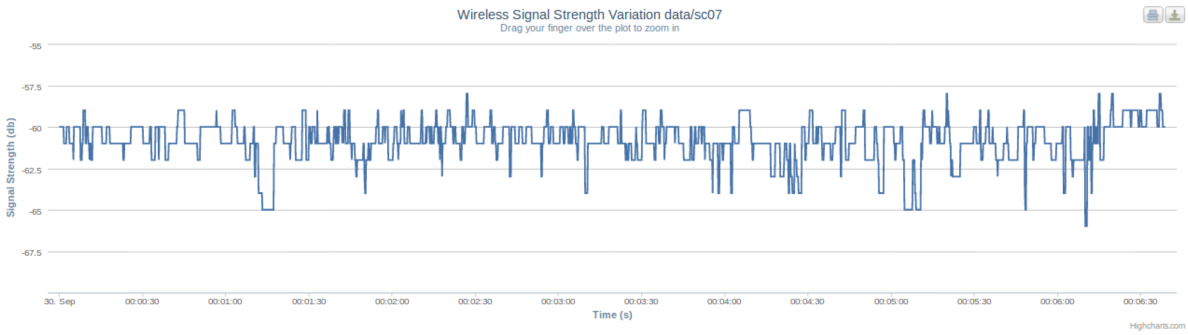


Figure 67 : Appendix C - RSSI data graphical output for SC07

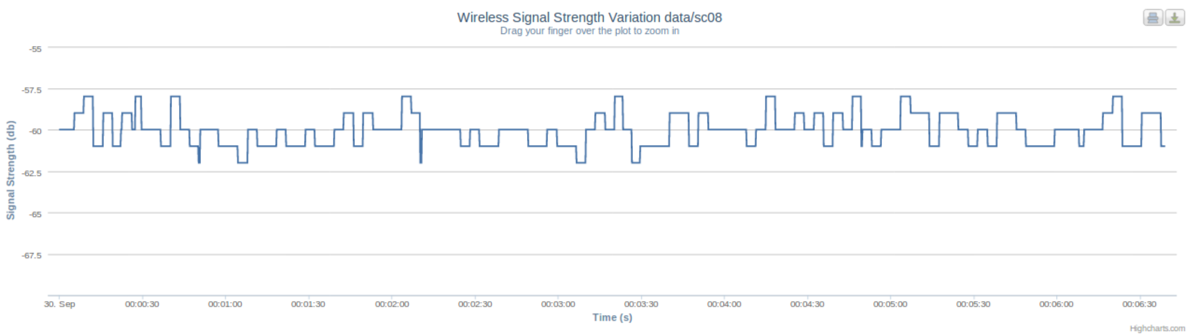


Figure 68 : Appendix C - RSSI data graphical output for SC08

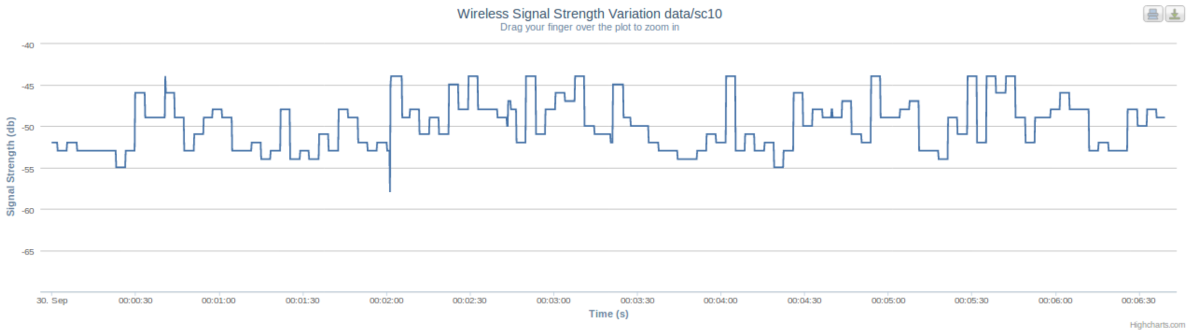


Figure 69 : Appendix C - RSSI data graphical output for SC10

Appendix D - Graphical output of SNR Data

Within this section the SNR value variation graphs are presented. Each figure contains five graphs sections. In the first graph, it show the SNR variation with window size 10, second with window size 20, third with window size 30, fourth one with window size 40 and the fifth one with window size 50.

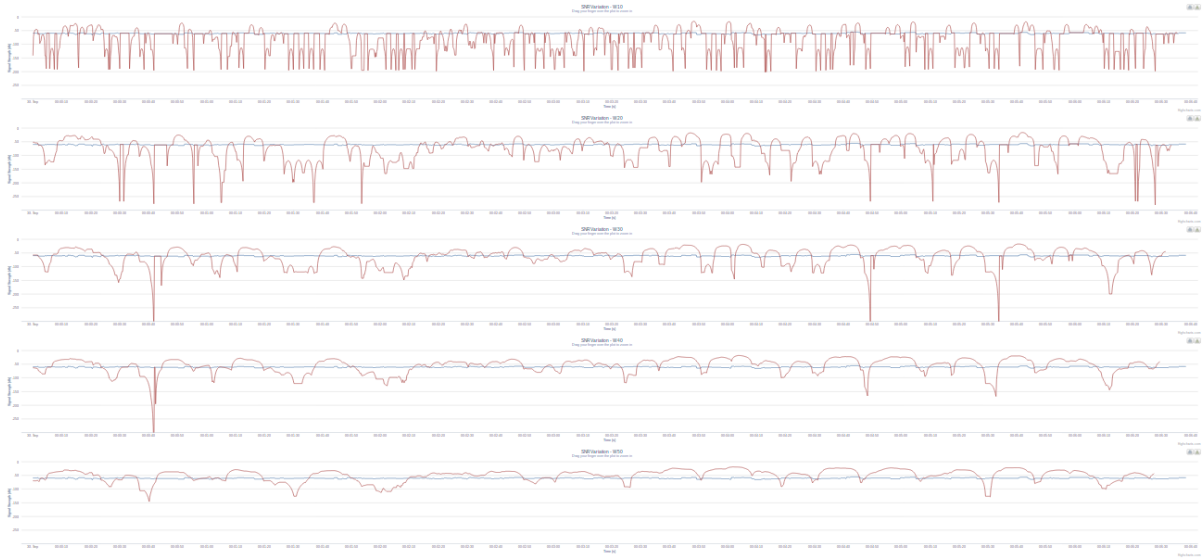


Figure 70 : Appendix D - SC02 SNR value variation for difference window sizes.

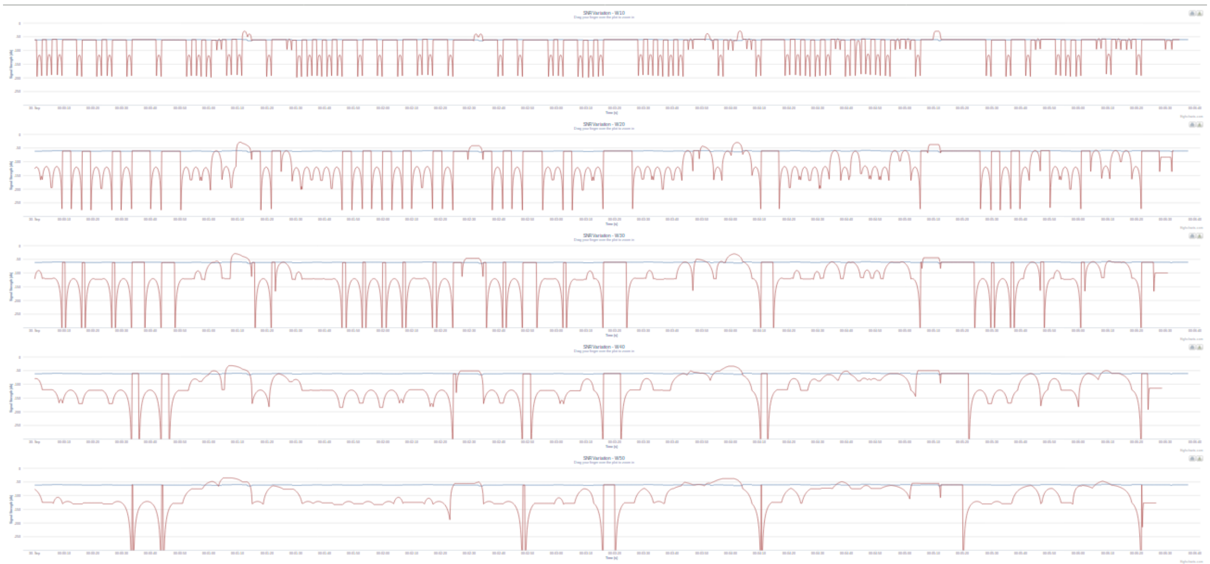


Figure 71 : Appendix D - SC03 SNR value variation for difference window sizes

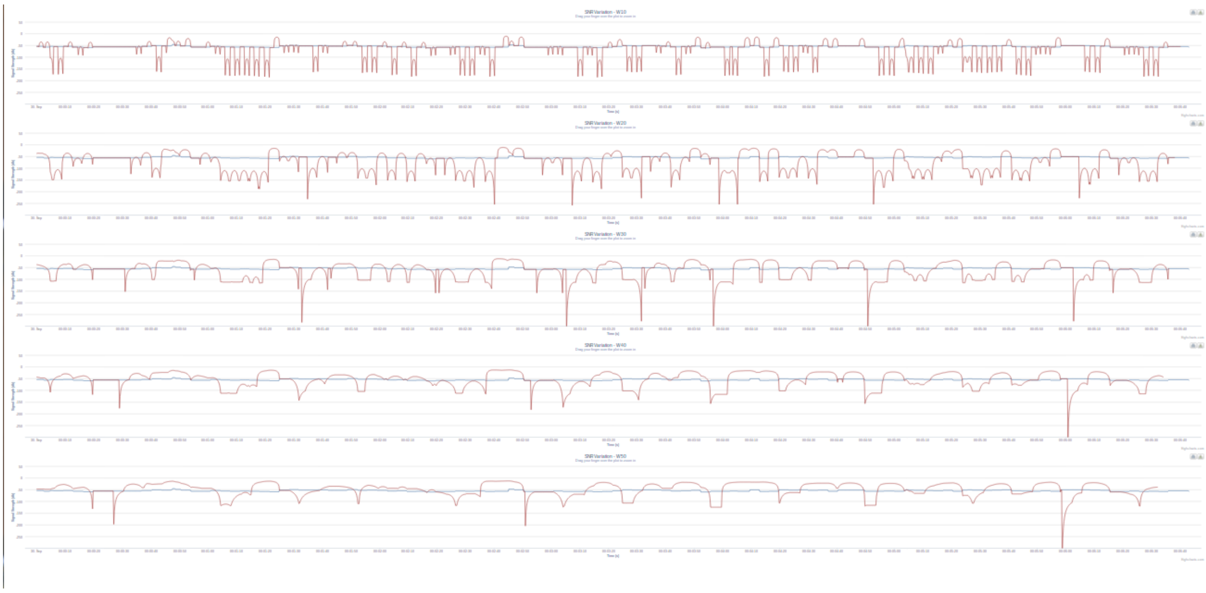


Figure 72 : Appendix D - SC04 SNR value variation for difference window sizes

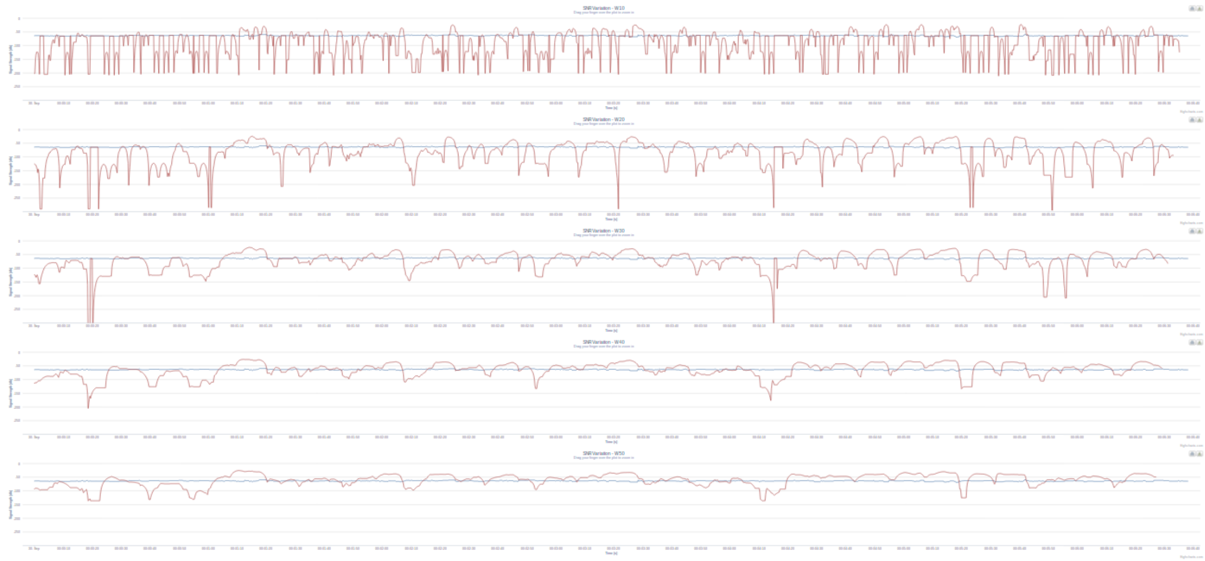


Figure 73 : Appendix D - SC05 SNR value variation for difference window sizes